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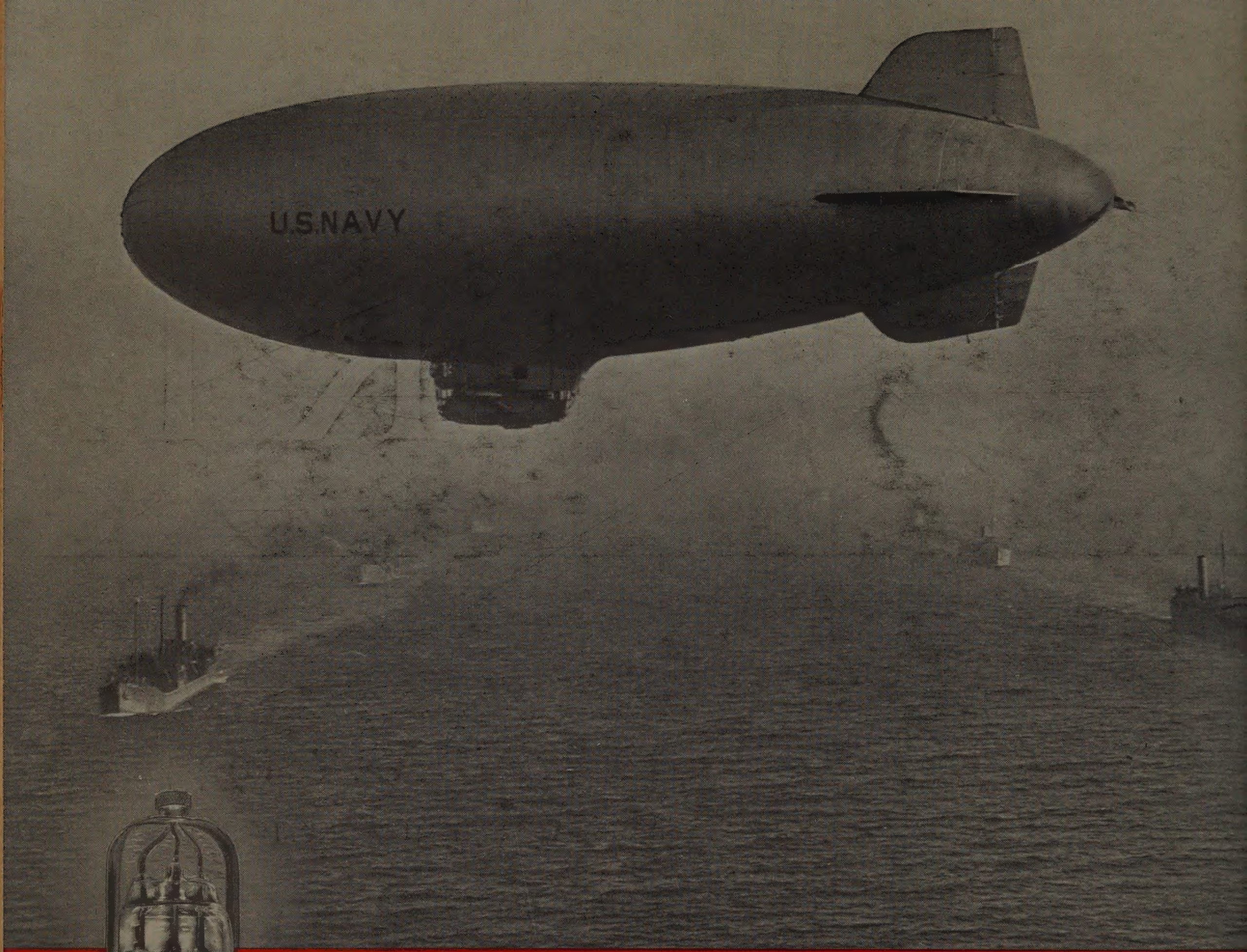

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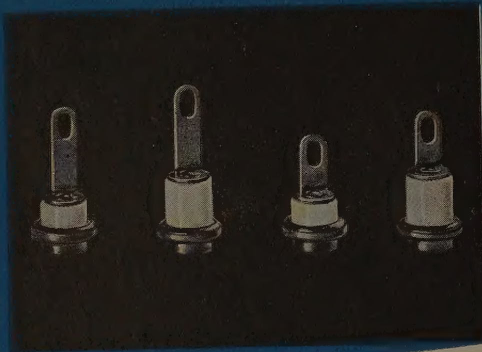

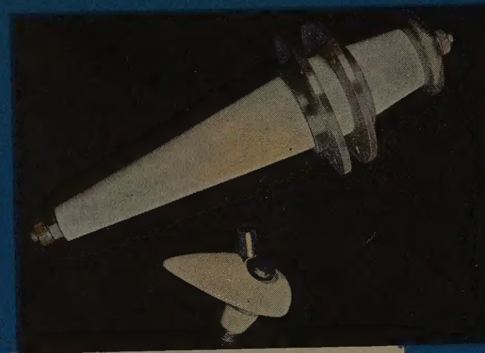

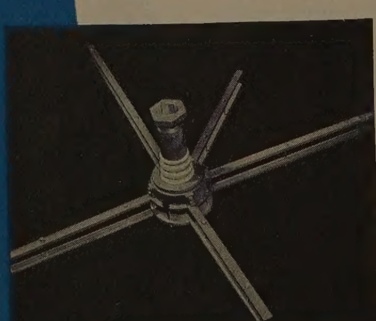

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Contemporary Problems in Television Sound*

C. L. TOWNSEND†, ASSOCIATE, I.R.E.

Summary—*The present rapid development of television is introducing new problems in sound pickup and operation. As the art progresses, engineering tools and methods must not only keep pace with, but generally anticipate, the needs of the program-producing staff in the production of more and more intricate material. The nature of the acoustic problems so raised, and their solutions, are treated in this paper. New tools necessary to proper operation and the methods of their employment are discussed. For a better understanding of television requirements, the methods normally employed in motion pictures and standard radio broadcasting are compared with those in use in the present television studio. Some indications as to what may be required in the near future are discussed and possible developments suitable for such use are described.*

IN THE history of every new activity, problems and concepts peculiar to itself arise. Certainly television is no exception to this rule nor is that part of television which we are to consider. There may have been many who felt in the earlier days of the art that television's sound accompaniment could well be expected to care for itself, for much had been done to perfect a technique of sound pickup with action in progress in the motion-picture studios of Hollywood. But very shortly, marked departures from the accepted methods were found desirable, and gradually it became clear that good television sound required not only different treatment but also different tools than were used at first. As the show-producing workers in television become familiar with their picture-making

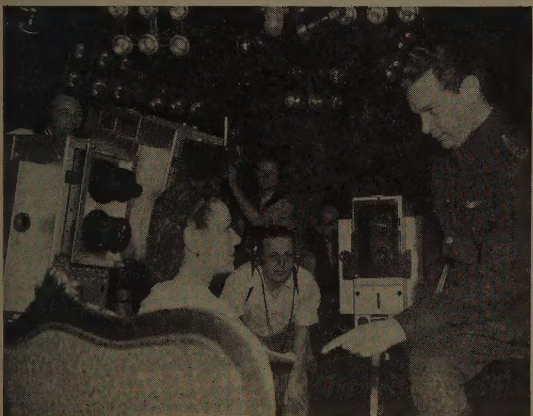

Fig. 1—For good pictures, television cameras require most of the space. Sound equipment must operate in what remains.

equipment, more and more is being demanded of it, and the sound accompaniment must keep pace. No consideration of the sound portion of a problem arising in a television studio is permitted to interfere with the picture technique, since the production staff has come to rely upon the sound engineer to find a way around his difficulties. This paper discusses these difficulties, and considers what may be done to overcome them.

A consideration of the mechanics of television studio operation will disclose some of the problems arising in sound pickup associated with visual programs. The National Broadcasting Company's studio is equipped at present with three television cameras and normal set lighting requires the use of four floor broads of about 3 kilowatts each. All of this equipment must be positioned for best advantage as to camera angles and lighting effects. If no sound equipment were used at all, the portion of the studio in use would be crowded

Fig. 2—Efficient utilization of floor space is a necessity in television.

enough, but it is necessary for the microphone boom to find a place also. The boom operator chooses his position with regard not only to his own best sound requirements but also considers the possible camera movements. If it is likely that a camera-dolly movement will find him in its way, he must be able to move the base of the boom sufficiently in advance of the dolly to clear the necessary space. Thus, the boom operator must not only follow closely the action on the set but must also bear in mind the exact pattern of off-stage activities. The present operators have become adept at maintaining the position of the microphone correctly above the heads of the persons on picture, while stepping from the boom platform and moving it bodily a sufficient distance to permit passage of a camera. Often, too, only a few seconds can be allowed for a complete change from one set to another, necessitating accurate planning of movements and precise co-operation between sound- and sight-equipment personnel. To aid in this the boom used is as small as is presently practicable, having a maximum extension of 14 feet and being about 4 feet wide across the base. A unidirectional microphone is used to aid in reducing off-set noise, but this adds to the

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† National Broadcasting Company, New York, N. Y.

precision necessary in operation, for if close-ups are being used, the microphone must be aimed at the person being televised. This means that the boom operator must watch the camera-switching lights and position the microphone to suit the camera as well as the actor, being careful to discriminate against off-camera sounds only.

To facilitate scene transitions, or to provide a second pickup in a set where two widely spaced sound sources act concurrently, a method of hanging micro-

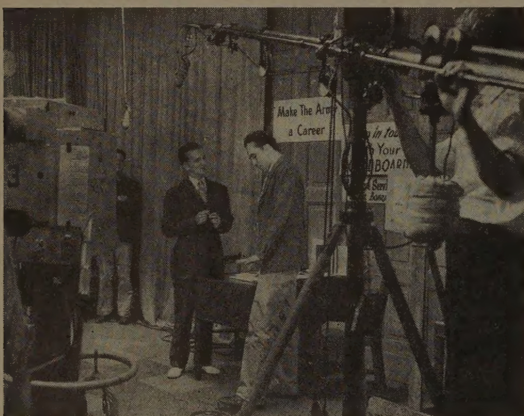

Fig. 3—A transition from one scene to another may require the use of a fixed-position microphone for opening the new scene. Action will be restricted until the arrival of the boom microphone.

phones has been devised. The studio ceiling carries a network of pipes of approximately $2\frac{1}{2}$ inches in diameter. A special clamp has been made to fit these pipes. Connected to each clamp is an adjustable length of light conduit, designed to accept a standard microphone coupling. The clamp can be operated by twisting the conduit making it unnecessary to climb ladders to hang microphones; this greatly increases the all-important factor of speed.

Three types of microphones are normally used in the National Broadcasting Company's television studio. The unidirectional type with a cardioid pickup pattern is used for dialogue, mainly because of its ability to reduce the effect of off-stage noise. Television, unavoidably, has rather more of this than is used on a motion-picture sound stage, since following scenes must be prepared, equipment moved continuously to new locations, and the show kept running generally. This contrasts markedly with the complete stopping of all other activity when a scene is made in motion pictures. Regular velocity microphones are used in cases requiring more reverberation, or when convenient to use both sides for pickup. Usually this occurs when music is used on the set, and an acoustically bright effect is desired. A pressure microphone is used when its nondirectional characteristic is advantageous. The production staff at NBC recognizes that in recent years a microphone has become an integral part of some scenes. A supper-club set may call for several microphones, and if a grouping dictated by picture requirements is too wide for other types, a pressure microphone will solve the problem. As these microphones are relatively small, they are also most suitable for use in positions where they might tend to obscure the picture, or when a microphone must be held in the hand.

Even with the above variety of tools, situations arise that defy ordinary "on-the-spot" pickups. These cases generally can be classified into those in which high scenes limit the possibility of bringing a microphone close to the action, and those in which the action is too fast or too complicated to permit its being followed by the microphone boom. Both occur usually in the musical production type of scene. It may be that a large and decorative background has been erected for a solo song, center stage and low. Obviously, no reasonable balance can be obtained between voice and accompaniment if the microphone must be far enough away to be out of the picture when it includes so large a backdrop. In the second case, trouble usually is encountered when performers not only sing but also move through a routine of action not suited to sound pickup. This may include singing while facing away from the camera, or while moving through a doorway, or per-

Fig. 4—Musicians must be close to the set for good musical coordination, introducing problems in balance and overlapping pickups. Unidirectional microphones aid greatly in such situations.

haps next to percussion instruments of an orchestra where maintenance of balance would be impossible. All of these situations call for prerecording, a technique developed in Hollywood and happily adaptable to television. Two methods of procedure are available. In the first type mentioned above, the microphone is located in a suitable position for the making of the record, usually several hours before show time. The action is carried out as usual and the timing of the record automatically fits the scene as it will be

broadcast. When the actual show takes place, a cue from the production director will start the record and kill all sound pickup in the studio. The record is then not only put on the air, but also fed back into the studio, where the performers can hear it, and synchronize their actions to it. When the recorded portion ends, the studio microphones are opened and the show continues normally. In the second type mentioned, the action is too detrimental to sound pickup to permit recording with it in progress even though no picture is required. Hence the action is carefully timed and cues noted. The recording will then be made without action, the setup being entirely to suit the sound situation. Such a record is then checked for synchronism on another rehearsal, and used "on the air" as described. A lacquer disk recording with the NBC Orthacoustic characteristic is used, resulting in transitions from direct pickup to record and back again with practically no noticeable change in sound quality. With such satisfactory matching of sound quality available, prerecording is a very useful tool in television.

Another angle of the studio-mechanics problem is in peculiar contradiction to the case in motion pictures. In some instances, the motion-picture-making equipment causes some trouble through making noise which may interfere with the desired sounds. In television the reverse is true. Sound in the studio may be of such intensity and frequency that it will cause spurious signals due to microphonics to appear in the picture. These generally consist of horizontal bars across the picture, and result from vibration of elements of vacuum tubes used in the video preamplifier in the camera. It is necessary to treat the television camera to keep sound out, rather than in. A heavy material, similar to roofing felt may be cemented to the inside surfaces of the camera housing to reduce sound transmission, and particularly to damp vibration occurring in the large plane sections of the present camera's sides and top. Without such damping, these parts will vibrate very heavily at their natural periods, making sound crossover almost a certainty. With sufficient loading the tendency to vibrate disappears almost completely, permitting operation with any normal studio sound level.

The very nature of television is that its appeal must be in the intimate manner. As long as the present methods of picture reproduction are being used extensively, this will continue to be the case, for picture size and detail make best use of close-ups and penalize the extreme long shots. The sound that accompanies these pictures should partake of the same quality, heightening the tone and mood of a scene. The methods adopted and the tools used must, then, be suitable for such work.

The National Broadcasting Company's live-talent studio is a room $30\times50\times17$ feet. Its acoustic treatment differs radically from what a motion-picture engineer might expect to find on a sound stage, in that the reverberation constant is not as short as it could be made, but rather a variable quantity, being in some cases as long as $1\frac{1}{4}$ seconds, and in others as short as $\frac{1}{2}$ second (over the essential range of frequencies). The reasons for this are close to the heart of the television problem. In the usual sound-stage case, the studio is a large acoustically dead room, in which relatively permanent sets are erected. It is normally the intention to permit those sets to exhibit their own characteristic reverberation without much, if any, artificial reinforcement. The case in television is somewhat different. Our sets are designed for rapid scene changes, and efficient use of personnel. They are made of linen stretched on wood frames in the manner of legitimate stage scenery. Instead of adding a lifelike reverberation to the sound originating in them, such sets produce undesirable low-frequency resonance effects, and add large amounts of high-frequency absorption in their unpainted surfaces. If the studio itself were very "dead" these effects would add detrimentally. Dialogue equalizers are used, which help to avoid this trouble, but the less equalization that can be employed, the better will be the average sound quality.

Studio acoustics also play an important part in television sound for other reasons. The volume of the sets in use is always a very large portion of the total studio volume, since many scenes must be set up at once to provide a continuous performance. Under usual conditions almost the whole studio is used in a show to run an hour and a half. With so much absorption added in the sets, much of the original treatment of the studio must be removed to produce anything like normal reverberation. Most television shows will also present music as well as speech in the same studio, without a pause between the two portions of the program. Such a case in motion-picture production would call for the use of a scoring stage, or a set especially treated for music. In television, the problem is attacked by making large sections of the acoustic treatment on the studio walls movable. These panels can be opened to expose a hard, reflective surface, increasing the reverberation to an acceptable level. Should an outdoor scene be required, however, all the absorbing panels would be closed, and equalization added to produce an essentially reverberation-free pick-up.

It has often been remarked that television even now should use large studios of the motion-picture sound-stage variety. There are however certain mechanical and acoustical considerations that make this doubtful. Present television practice, which demands many close-ups and rather restricted action during most of the show, means that even with a relatively large set, for the major portion of a "take," the cameras, lights, and sound equipment must be crowded together to serve best the particular portion of it used at the moment. It is a provoking fact that although most of the studio may be empty, the television equipment must be worked in close quarters. Consequently, additional

room would not materially increase the freedom of action of the cameras as far as any one set is concerned. Mechanical considerations, then, indicate that the size of the studio is determined by the number of sets which reasonably can be used on one show, or can be served by one group of equipment. Under present production conditions, this would result in a studio considerably smaller than the larger motion-picture sound stages. Acoustically, the smaller studio is desirable, because of the requirement mentioned above that

Fig. 5—Making close-ups and long shots simultaneously introduce problems of acoustic realism.

studio acoustics be adjustable to compensate for set absorption. If the studio becomes too large, it cannot contribute usefully to the over-all sound quality, for reverberation as a desirable enhancement is replaced by what is commonly called room-slap, or echo. Hence, if a very large studio is to be used, it *must* be very "dead," which inflexibility seriously limits its usefulness as an acoustic tool. The answer to this problem seems to be that television studios should be of a size between those used in radio broadcasting and the large stages of Hollywood if all the mechanical and acoustical advantages are to be realized.

The excellent work currently done in the broadcasting studios has raised to a high stage of refinement the art of producing mood and atmosphere with sound. Television must offer at least as much facility for creation of these effects and at the same time must not limit in any way the freedom of action necessary to good pictorial effect. Some of the problems encountered in this blending of sound technique and sight productions are worthy of consideration.

In the television studio, both close-up and long shots must be taken at the same time. The accompanying sound must not only suit the apparent distances shown in the picture, but may also be required to produce an effect complementary to it. At times, perspective in television sound is so important that what would normally be only a medium long shot can be made to *seem* very long, if the sound which accompanies it carries sufficient reverberation to suggest great distance to the mind of the listener. Since actual long shots are not usually permitted for long periods of time, such an aid in producing the effect of distance is a valuable tool. Close-ups, of course, require intimate sound, and often the change from a distant view to a close-up occurs too quickly to permit any actual change in microphone placement or acoustic treatment, so the *effect* of a change must be produced electrically. Reverberation once added cannot be deleted; consequently, the pickup conditions must be set to produce close-up sound. It is then possible to add reverberation through the use of the standard echo-chamber method. In the studio, close-up cameras are provided with long-focal-length lenses, and long-shot cameras have either normal- or short-focus lenses. Switching between the cameras actuates a set of relays so connected that amounts of reverberation and volume level can be adjusted to suit the lens of the camera in use. This is accomplished by providing for each camera a separate volume control, and a separate reverberation control. If a camera is to be used to take a long shot, the volume control associated with it is turned down an amount calculated to produce the proper psychological effect, and the reverberation control is opened to accept a large portion of the output of the echo chamber. Another camera having an intermediate focal length would use more direct sound and less reverberation, while the close-up camera would use full volume and no feed from the echo chamber at all. When the technical director switches from one camera to another, the sound is also switched from one set of controls to another, producing instantaneous changes in sound quality to suit the picture requirements. Of course such artificial correction is confined in its application to interior shots which would normally exhibit acoustical characteristics similar to those available from the echo chamber. Corrections can be applied to outdoor scenes by changing the volume level and low-frequency response of the system to match the camera switching. Thus an exterior long shot would be accompanied by a reduction in volume-control setting and an increase of equalization designed to remove low and high frequencies, thus simulating the conditions obtaining in nature. Without such processing, the sound accompanying a television picture would not only lose valuable contributing effects, but at times might give an almost ludicrous effect, for the human eye and ear have been trained to expect a certain correlation between sight and sound perspective, and violations of their normal relationships are not acceptable.

Another problem peculiar to television sound is the result of a demand for realism in its dynamic range. In motion pictures, the acceptable range of loudness is a strictly measurable and controllable quantity. The lowest modulation permitted is a function of track hiss, frequency response, audience noise, etc., and the

highest sound output is determined by the 100 per cent modulation point and reproducer power. No one in the audience is able to change the volume reaching him, nor does he expect to hear sound which is not dimensioned to fit the picture on view. In radio broadcasting, almost the exact opposite is true. With no visual program, the listener demands the maintenance of a relatively constant level, and often writes to his station complaining that he has to adjust his receiver volume control during the progress of a show. Television encounters portions of both of these troubles, and has had to evolve its own operating procedures to combat them. Since television is broadcast, a reasonably high average modulation should be maintained, in order that receiver noise levels may be low. Maximum deviation is determined, of course, by channel width. Within these two extremes must be confined sound to suit anything from the scraping of a pen across paper, to the crashing thunder of a modern blitzkrieg. Such matching of sound and sight is necessary, for if the eye sees what would in nature produce a loud sound, but the ear hears only a small, muted version of what is expected, the mind rejects both sight and sound as being counterfeit. Thus a dynamic range is required of television sound which is greater than absolutely necessary in sound broadcasting. Here the home receiver enters the problem. If dialogue, and other relatively quiet sounds, are broadcast at their proper level over a period of time, it is likely that the volume of the home receiver will be increased by the listener to match what has come to be expected of broadcast sound. Then, if full dynamic range is employed, the louder passages will exceed reasonable living-room power, or perhaps overload the receiver. Hence, some compression must be employed, yet without producing the above-mentioned unconvincing mismatch. Treatment of this problem has evolved into a skillful handling of audio levels in such a way as to produce changes in apparent loudness which are greater than those actually broadcast. If it is known in advance that some particular point in a performance will require a large increase in volume, the loudness of the passages preceding the expected increase in level is gradually lowered, the process sometimes extending over several minutes. This decrease in loudness is accomplished so slowly that it does not come to the attention of the listener and is in some degree compensated by what appears to be an increase in the listener's aural sensitivity. Then, when the large amplitude is required, an increase to maximum deviation is sufficient to produce an admirable effect. Of course, such a loud period causes the listener's hearing again to be reduced, and care must be exercised in returning to a medium or low level of modulation.

The television sound problems which have been discussed are a few of those that have already been encountered in television broadcast operation. They have increased in complexity as television program production has advanced its techniques. In an art developing as rapidly as television, no one can be certain that indicated trends will be followed or that present methods and materials will be adequate, or even useful, in the future. It is only by continuing the present close cooperation between the studio and the development laboratory that television's sound problems can be solved.

Automatic Frequency and Phase Control of Synchronization in Television Receivers*

K. R. WENDT†, ASSOCIATE, I.R.E., AND G. L. FREDENDALL†, ASSOCIATE, I.R.E.

Summary—*One of the problems in the reception of television images is to provide satisfactory synchronization in the presence of noise. During the past several years considerable experience has been gained with respect to this problem under various receiving conditions. The system of synchronization which has given satisfactory results up to the present time has depended for its operation on the reception and separation of individual pulses. In general, it can be said that with this system satisfactory synchronization can be obtained from those signals which will in all other respects provide an entirely acceptable picture. However, for limiting conditions of service, particularly during early operation where field strength may be low, an improvement in synchronization will be effective and desirable provided that it does not involve other complications or disadvantages.*

This paper describes a synchronizing means at the receiver that employs a new principle in the field of synchronization. The principle is automatic frequency and phase control of the saw-tooth scanning voltages. In such a system, synchronization depends on the average of many regularly recurring synchronizing pulses. Noise has insufficient energy at the scanning frequencies to effect control through the direct-current link from which all but relatively long-time variations are filtered out.

Experimental receivers, in which automatic phase and frequency control of the scanning oscillators has been incorporated, have operated with high immunity to noise. The degree of immunity is of a different order of magnitude from that found in conventional synchronizing systems.

Noise cannot affect horizontal resolution or interlacing. An intrinsic property of the new system is perfect interlacing. The return line in an automatic-frequency-controlled system may start before synchronization.

Consideration of this new development indicates that its use would result in several improvements in television service: (1) when severe noise conditions occur, an improved picture is obtainable at points within the present service area; (2) under such noise conditions, the useful service area is extended; (3) the maximum resolution permitted by a television channel is realizable at locations having low field strengths. It is expected that these improved results will be attained without increase in the cost of the television receiver.

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† RCA Laboratories, Princeton, N. J.

Conventional Synchronizing Systems

In the operation of present commercial television receivers, the natural frequencies of the horizontal and vertical scanning oscillators, in the absence of a synchronizing signal, are lower than the line or field frequencies, respectively, at the transmitter. The application of a transmitted pulse initiates or "triggers" a new cycle of the oscillator before one would otherwise occur. The period of the horizontal-scanning oscillator is shortened to conform to line frequency and the period of the vertical oscillator to field frequency. Thus, triggering is required for each successive horizontal and vertical scan. This is the basic principle of operation of conventional synchronizing systems.

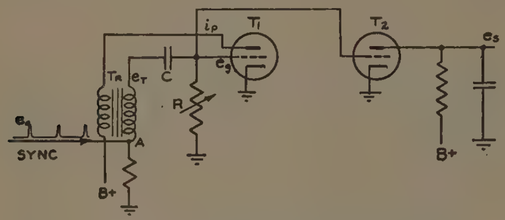


Fig. 1—Conventional triggered scanning oscillator.

Fig. 1 shows a scanning oscillator of a typical commercial television receiver. A cycle of operation in the absence of a synchronizing signal is shown in Fig. 2. As the grid potential e_g of the tube T_1 reaches the cutoff point as a consequence of leakage of charge through resistance R from the previously charged capacitance C, plate current i_p begins to flow. A short time later, the induced voltage e_t causes the capacitance C to take a large charge which, in turn, lowers e_g to a high negative value. Plate current does not flow again until sufficient current has leaked through R. The excursions of e_g above the cutoff point of the tube T_2 are responsible for the generation of a saw-tooth wave e_s in the plate circuit of that tube.

Assume now that a synchronizing pulse e_0 is applied between point A and ground in Fig. 1. The effect is a premature rise of the potential e_g to the cutoff voltage of T_1 as shown in full lines in Fig. 3a. A pulse of plate current i_p occurs earlier than in the absence of a synchronizing signal. The dotted wave in Fig. 3a shows the variations of currents and voltages in the absence of a pulse as in Fig. 2. Wave e_s may represent current variations in the coils of an electromagnetically deflected tube or voltage variations across the plates of an electrostatically deflected tube.

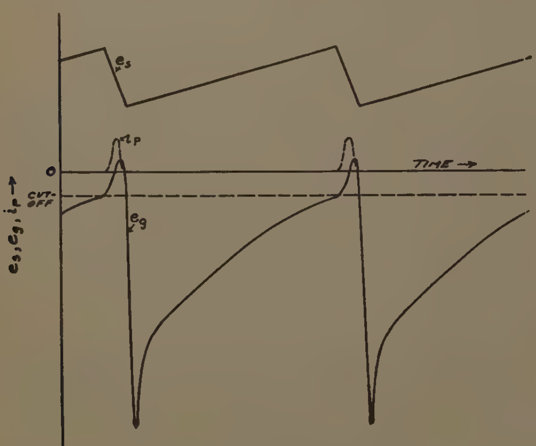
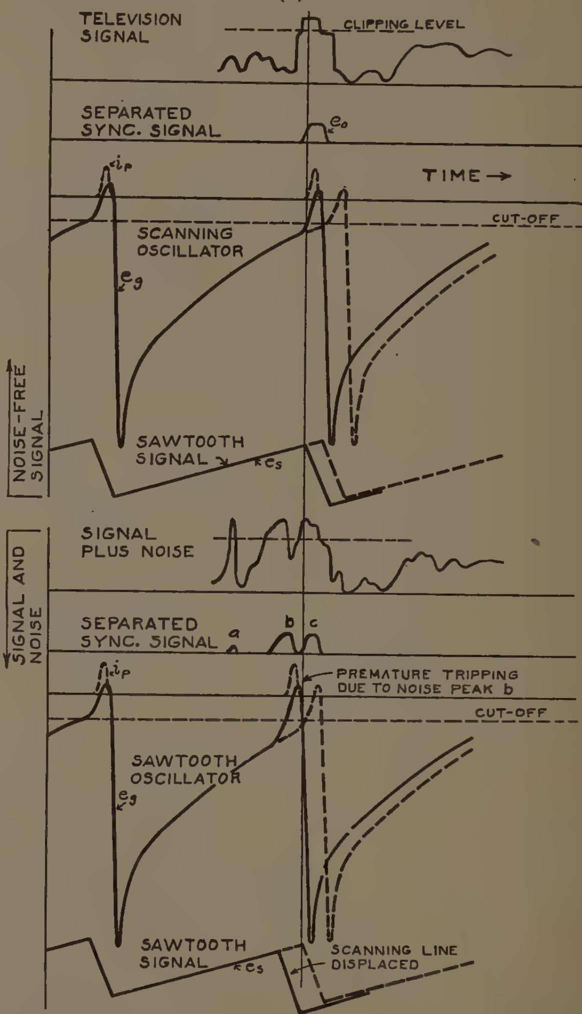


Fig. 2—Operation of the scanning oscillator.

(a)



(b)

Fig. 3

(a)—Operation of scanning oscillator.
(b)—Operation of scanning oscillator when noise is present.

The behavior of the triggered oscillator when noise is present in the signal is the primary interest here. Hence, we shall wish to determine how the frequency or phase of the scanning voltages are affected when the picture signal is accompanied by noise peaks which

exceed black level and therefore appear in the synchronizing signal as shown in Fig. 3b. Noise peak "a" superimposed on the normal grid potential e_g curve is insufficient to raise the potential above the cutoff of tube T_1; hence, the peak is ignored by the oscillator. Noise peak "b," however, does have sufficient amplitude to cause e_g to rise above the cutoff potential, and therefore initiates a new cycle of oscillation prematurely. The legitimate synchronizing pulse at "c" would have caused the normal cycle shown in dashed lines. The deflection signal e_s shown in full lines corresponds to the premature synchronization. The dashed lines represent the desired signal.

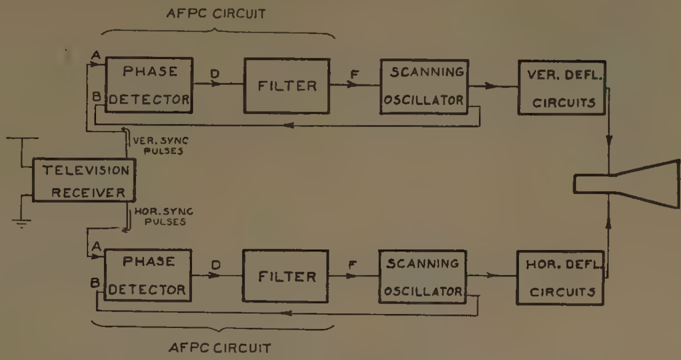


Fig. 4—Block diagram of an automatic frequency- and phase-controlled system.

If e_s represents the horizontal-deflection signal, the observer interprets the misplacement of e_s as a line out of the normal position on the viewing screen. If e_s represents the vertical deflection signal, he observes a vertical movement of the picture.

It will be realized that the immunity of the system to noise is least when e_g is near cutoff because lower noise peaks are sufficient to initiate a new cycle of the oscillator. In the event that a synchronizing pulse is obliterated by noise, the oscillator may remain inactive until e_g reaches the cutoff potential of the tube and thus initiates a new cycle which is late relative to the normal position. It is clear, therefore, that triggered synchronizing as described above is subject to noise limitations that are inherent in the principle of operation.

Automatic Frequency- and Phase-Controlled Synchronizing Systems

Fig. 4 is a block diagram of the essential components of an automatic frequency- and phase-controlled synchronizing system. Since the same principle is involved in the operation of the horizontal and vertical circuits, it is unnecessary to specify a particular circuit. The phase detector receives the synchronizing signal at A and a saw-tooth wave at B taken from the output of the scanning oscillator. A control voltage produced at D by the phase detector contains information regarding the phase of the saw-tooth wave relative to the synchronizing pulses. The phase detectors described below respond to changes in relative phase that may exist at the time of arrival of each pulse. However, only the slowly varying components of the control voltage are passed by the filter following the phase detector. Rapid variations corresponding to rapid or erratic changes in relative phase are eliminated. Thus, the control voltage at F may be regarded as a direct voltage which is applied to the scanning oscillator in order to restore the phase of the oscillator relative to the synchronizing pulses when there is a long-time trend in phase away from the equilibrium state established by the speed control of the scanning oscillator. Such changes in phase and frequency of the saw-tooth as occur as a result of the action of the control voltage are conducted back to the phase detector through the feedback path in order to provide further correction.

In the presence of noise of sufficient magnitude, the phase detector may register the relative phase of a noise peak and the corresponding saw-tooth cycle. Such spurious components in the control voltages at D usually lie in the range of frequencies beyond cutoff of the filter and are therefore effectively removed from the voltage at F. The noise immunity of automatic frequency- and phase-controlled circuits is a consequence largely of the action of the filter. Further insight into the theory of automatic frequency- and phase-controlled synchronization may be obtained from a more detailed account of the operation of specific circuits.

Fig. 5 shows a circuit which may be used for automatic frequency and phase control of a horizontal or a vertical oscillator. Here, synchronizing pulses are supplied to the terminals A_1-A_2 of the phase detector by means of a balanced circuit. A fraction of the output of the scanning oscillator is introduced at point B of the phase detector in order to form the composite

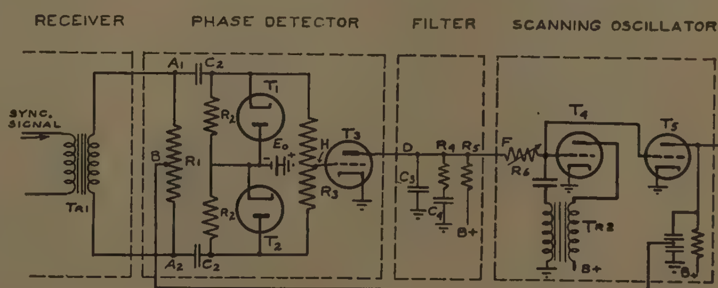


Fig. 5—Automatic frequency- and phase-controlled circuit.

signals shown in Fig. 6(a) and (b). In practice, when the automatic frequency- and phase-controlled system is in equilibrium, the synchronizing pulse must occur sometime during the return line, that is, during the steep portion of the saw-tooth wave. This restriction

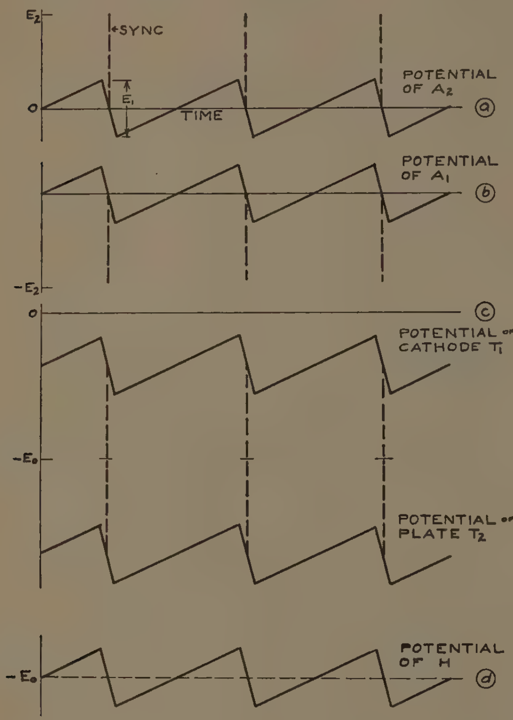


Fig. 6—Composite signals for possible equilibrium position.

is necessary for the viewing of a television picture in the correctly framed position on the screen of the cathode-ray tube.

If it is assumed that a state of equilibrium is attained, the condition is maintained in the following manner. Tubes T_1 and T_2 are diode rectifiers which may be idealized for simplicity of explanation. We shall assume that the circuit composed of the resistance R_2 and the capacitance C_2, associated with the diode T_1, maintains a potential variation (Fig. 6(c)) at the cathode of the diode that resembles the wave in Fig. 6b in every respect except that the peak amplitudes of the pulses are definitely located at $-E_0$ volts. In popular terms, the diode is said to "set direct current." The values of R_2 and C_2 must be chosen with the view of causing T_1 to act as a direct-current setter or peak rectifier.

In a similar manner, the diode T_2 in combination with its associated elements R_2 and C_2 maintains the potential variation at the plate of T_2 as shown in Fig. 6c in which the peak amplitude of the synchronizing pulse is maintained at a potential of $-E$ volts with respect to ground. The potential with respect to ground of the mid-point of the resistance R_3 shown in Fig. 6(d) is the average of the potentials at the end points of R_3. An important observation to be made in Fig. 6(d) is that the synchronizing signal is balanced out. This leads to the conclusion that the waveform and the direct-current component of the signal at point D are independent of the amplitude assumed for the synchronizing signal, but that the direct-current component is dependent upon the phase relation of the synchronizing signal and saw-tooth wave.

The low-pass filter in the plate circuit of the amplifier tube T_3 transmits the direct-current component of the signal at point D and greatly attenuates the alternating-current components. The amplified direct-current component or control signal at point F is applied as a positive bias to the grid of the scanning oscillator tube T_4. The frequency of the oscillator is a function of the grid bias. Consequently, the saw-tooth wave generated by tube T_5 has a frequency controlled by the resistance R_6 and the control voltage at point F. This signal is applied to the phase detector at point B by way of the feedback path.

The capability of the circuit for controlling the frequency and phase of the saw-tooth wave may be understood with the aid of Fig. 7. Assume, as was done above, that Fig. 6 expresses a state of equilibrium in the circuit and that the frequency and phase of the saw-tooth will remain indefinitely as shown if the

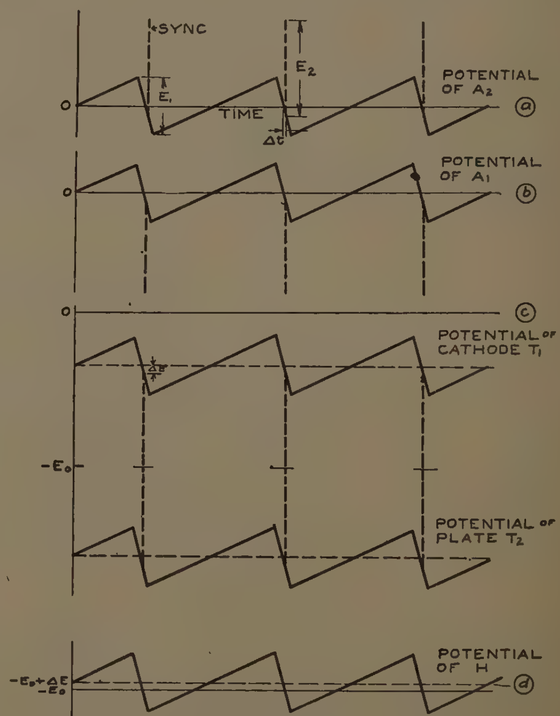


Fig. 7—Phase of saw-tooth delayed from equilibrium position of Fig. 6.

circuit is not disturbed. Let Fig. 7(a) represent a departure from the equilibrium condition as a result of some disturbance such as a drifting in the values of circuit constants or voltages. The relative phase of the synchronizing signal and the saw-tooth wave differs from the equilibrium phase relation (Fig. 6(a)) by an amount ΔT. As before, the peak rectifiers hold the peaks of the synchronizing signal at a potential $-E_0$. Hence, the alternating-current axis of the control signal at point H (Fig. 7(d)) is lowered by an amount ΔE. The direct-current component at point H therefore amounts to $-(E_0+\Delta E)$ volts or an increment of $-\Delta E$ volts over the equilibrium value in Fig. 6(d). This increment tends to increase the frequency of the oscillator and thus to shift the saw-tooth wave toward the position of equilibrium. Similarly, a departure from equilibrium shown in Fig. 8(a) and (b) gives rise to an increment of $+\Delta E$ volts in the control voltage which acts to decrease the frequency of the oscillator and thus again restore the equilibrium of the circuit.

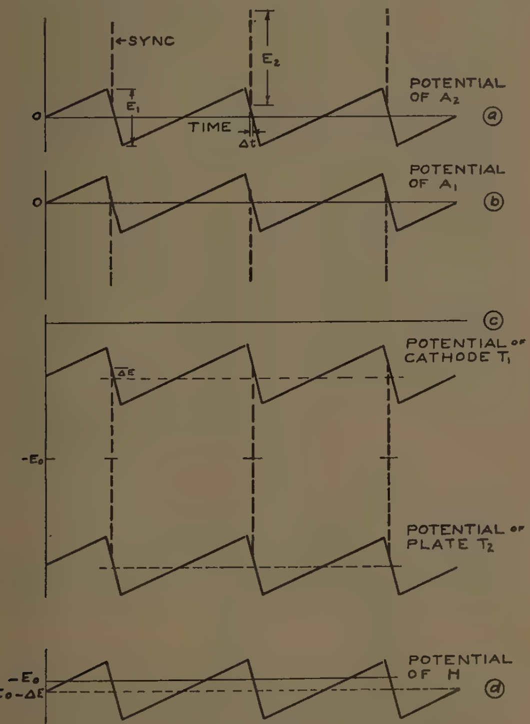


Fig. 8—Phase of saw-tooth advanced from equilibrium position of Fig. 6.

The amount of control or hold-in power available for overcoming phase and frequency deviations of the saw-tooth wave is proportional to the gain of the direct-current amplifier and to the difference between the direct-current components of the control signals at H corresponding to the two extreme phase conditions. Extreme conditions occur when a synchronizing pulse occurs either at the maximum or minimum points of the saw-tooth wave. This difference is equal to the amplitude of the saw-tooth signal introduced at point B except for negligible voltage drops in the phase-detecting circuit.

When noise is present in the synchronizing signal, the voltage across the terminals A_1-A_2 contains noise

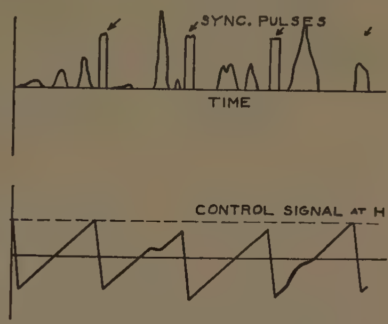


Fig. 9—Synchronizing signal and control signal when noise is present.

pulses which have been passed by the synchronizing separators as sketched in Fig. 9(a). The peak amplitude of some noise pulses exceed the bias voltage of the diodes and cause diode current to flow. Hence, the signal at point H resembles the erratic saw-tooth wave shown in Fig. 9(b) in which the noise pulses themselves are balanced out. The filter in the plate circuit of T_8 transmits only the direct-current component and the slowly varying components of the grid voltage. All components above a few cycles per second in frequency are effectively suppressed. The slowly varying components represent a persistent trend in the alternating-current axis away from the equilibrium position and give rise to a change in the control voltage applied to the oscillator. The resulting deviation in the phase and frequency of the oscillator is automatically minimized by the restoring effect of the automatic frequency- and phase-controlled circuit.

Almost identical constants have been used in the filters for the horizontal and vertical circuits. The response of the filter is reduced to about one third for a sine wave of 1 cycle per second and the response to 60 cycles is practically zero. Therefore, individual scanning lines cannot be perceptibly displaced with respect to neighboring lines. That is, the horizontal oscillator cannot respond to noise fast enough to impair horizontal resolution. In general, a triggered oscillator is sensitive to noise to an extent that horizontal resolution is decreased. Likewise the response to 30 cycles is so low that interlace is essentially perfect, even in the presence of severe noise or an imperfect vertical-synchronizing signal.

Another form of phase detector is shown in Fig. 10. This circuit uses four diodes and is inherently balanced, except for second-order effects. The circuit is more

complicated than the two-diode circuit of Fig. 5 but is somewhat easier to set up and adjust. The principle of operation is the same as the two-diode circuit, although the details are different, and a description can be given more easily in another manner. The four diodes may be considered as a single-pole single-throw switch which connects the output capacitance C_3 to the input circuit resistance R_2 during the synchronizing pulse interval. This is accomplished as follows: the four diodes may be considered as a bridge in which synchronizing pulses are applied in push-pull across the diagonal AB with polarities such as to cause current conduction in each diode. A direct-current biasing voltage, that maintains all diodes in the nonconducting stage during the intervals between pulses, is built up across the combination R_1C_1. This circuit is complete in itself; no battery is needed. The two corners C, D of the bridge are connected to the input and output circuits, respectively. It will be noted that each of these corners connect within the bridge to both a cathode and an anode. Thus, when the diodes are in a conducting state, current may flow in either direction between the input and output circuits. Capacitance C_3 in the output circuit receives a charge which brings the potential at point C nearly to the value existing at the input point D during the synchronizing pulse interval. This voltage will, of course, depend upon the phase of the synchronizing pulse and the saw-tooth signals.

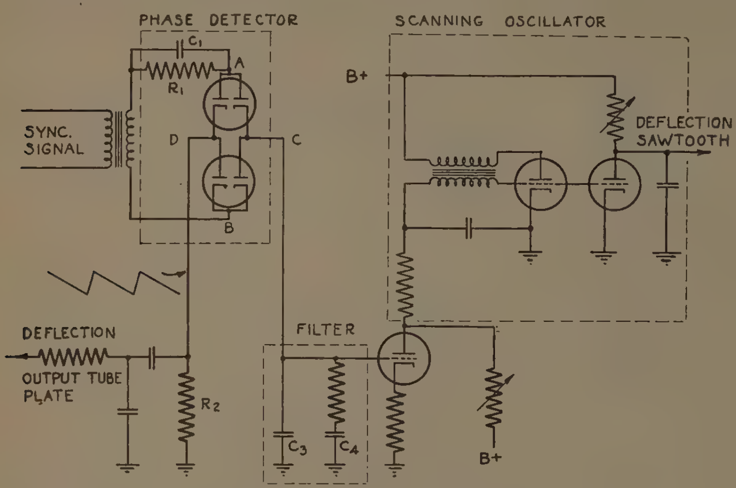


Fig. 10—Four-diode automatic frequency- and phase-controlled circuit.

In the circuit of Fig. 10, the signal at C contains neither of the input signals but only a direct-current component which is corrected once during each pulse in accordance with the phase relation between the input signals. This voltage controls the output of the direct-current amplifier which acts through the feedback loop and causes the phase of the saw-tooth wave to vary until an equilibrium is reached. This equilibrium occurs on the positive slope of the saw-tooth. In order that the phase relation for a properly framed picture shall exist, the saw-tooth applied at point D must have the polarity for which the return-line portion has a positive slope. The reason for this requirement may be seen by tracing the operation of the circuit. Assume that the local oscillator is out of equilibrium in such a direction that its frequency is low. The return line (positive slope) of the saw-tooth will occur late, as shown dotted in Fig. 11 and the synchronizing pulse will occur at a more negative point as shown at B, rather than at A. The potential of capacitance C_3 then becomes more negative and the plate of the amplifier tube becomes more positive with the result that the frequency is increased and the equilibrium restored.

The circuits shown in Figs. 5 and 10 require the application of saw-tooth signals of opposite polarity to the phase detector. Furthermore, the signal applied to the direct-current amplifier in Fig. 5 contains a saw-tooth component whereas the circuit of Fig. 10 does not. Either circuit could be changed to operate the same as the other in these two respects by reversing the input and output connections of the phase detector. There are many possible variations in phase detectors. However, the two described have been used satisfactorily and serve to illustrate the important characteristics of this portion of an automatic frequency- and phase-controlled system.

In an automatic frequency- and phase-controlled system there is an approximate equivalent to the degree of lock-in of a tripped oscillator. The tripped oscillator is locked in tighter when the amplitude of the synchronizing signal is increased. Greater susceptibility to noise is noticed in the tightly locked-in oscillator. In the automatic frequency- and phase-controlled system the amplitude of the synchronizing signal is relatively unimportant but the alternating-current gain from the phase detector to the oscillator influences the speed with which the oscillator may be changed in

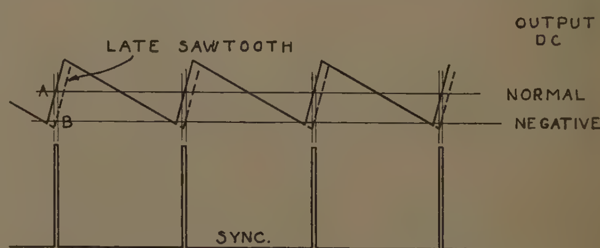


Fig. 11—Equilibrium and off-equilibrium conditions for four-diode circuit.

frequency, that is, the tightness of lock-in. If the automatic-frequency and phase-controlled oscillator can be shifted rapidly, relatively few pulses are required to obtain control and noise is averaged out over a short period. Conversely, if the gain is low, many consecutive pulses are necessary to obtain control and noise is averaged out over a long period, a condition which is obviously desirable. A low alternating-current gain, unfortunately, has another effect; i.e., when the receiver has just been turned on, or for some other reason is completely out of synchronism, the time for pulling into synchronism may be excessively long.

The mechanism of pull-in in an automatic frequency- and phase-controlled system may be outlined as follows: Assume that when no signal is received, the speed-control setting is such that the frequency of the oscillator deviates from synchronous frequency by a small amount. When a synchronizing signal is received, the phase detector generates an alternating-current wave, the frequency of which is the difference frequency of the synchronizing signal and the locally generated saw-tooth wave. If the difference frequency is attenuated strongly by the filter, there is little or no tendency for the oscillator to pull in since no direct-current control signal is generated. If the filter is such that some components of control voltage are passed without excessive phase shift and attenuation, the frequency of the oscillator tends to follow the instantaneous value of the control signal.

When the oscillator is pulled toward synchronism, the momentary difference frequency is decreased and the oscillator tends to remain longer in this phase than in the opposite phase during which the difference frequency is increased. This amounts to a distortion of the control signal which produces a new axis of the control voltage in the direction to pull the oscillator toward synchronism. The oscillator may be said to take three steps toward synchronism and two away, the sequence continuing until the deviations become sufficiently small and the oscillator falls into synchronism. Low phase shift through the filter and appreciable alternating-current gain are favorable for rapid pull-in. However, since the system employs a feedback loop, care must be taken to avoid self-oscillation. These requirements have led to the unusual filter, shown in Figs. 5 and 10.

An automatic frequency- and phase-controlled system, unlike a triggered system, is not limited to a single phase relationship between synchronizing and deflection. That is, the blanking bar may be caused to occur, tightly locked in, anywhere on the screen. This means that the deflection-return line may start at the beginning of the "front porch,"[1] ahead of the synchronizing pulse, thus greatly easing the return-line time requirements in the deflection system. Shifting of the blanking bar is accomplished as follows: Equilibrium, as previously stated, occurs with the synchronizing pulse located on the return line of the saw-tooth signal applied to the phase detector. This saw-tooth, however, need not be taken directly from the oscillator. The steep edge of the original saw-tooth wave may easily be delayed and, since the synchronizing pulse occurs in equilibrium on this delayed edge, the blanking bar must necessarily occur after the oscillator has tripped. An appropriate delay for horizontal deflection occurs automatically if the saw-tooth is made by integrating the pulse on the plate of the deflection tube, the delay being caused by the deflecting coil itself.

Experimental Receivers

Several experimental receivers incorporating automatic frequency- and phase-controlled circuits have been constructed. These have been tested both in the

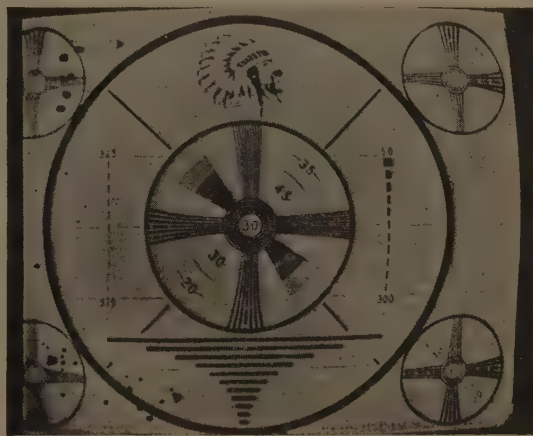


Fig. 12—Automatic frequency- and phase-controlled receiver—interference from high-frequency buzzer.

laboratory and the field and have given remarkably superior performance over conventional receivers for limiting conditions of service. Some pictures were taken in an attempt to show this difference but obviously it is impossible to convey accurately information regarding accuracy of synchronization by means of a still photograph. Fig. 12 shows a test pattern received by an automatic-frequency and phase-controlled receiver when operating with a signal above the hiss level but with interference from a high-frequency buzzer. The interference can be seen only as short black lines, and the figure serves mainly to show the resolution and interlace obtained essentially in the absence of noise. Exposure for this and the other test-pattern pictures was approximately 1/15 second, or 2 frames.

Figs. 13 and 14 are test patterns showing the relative synchronizing capabilities of a conventional receiver and an automatic frequency- and phase-controlled receiver in the presence of about equal amounts of hiss

[1] The term "front porch" refers to the part of the synchronizing signal between the beginning of the blanking signal and the front edge of the synchronizing pulse.

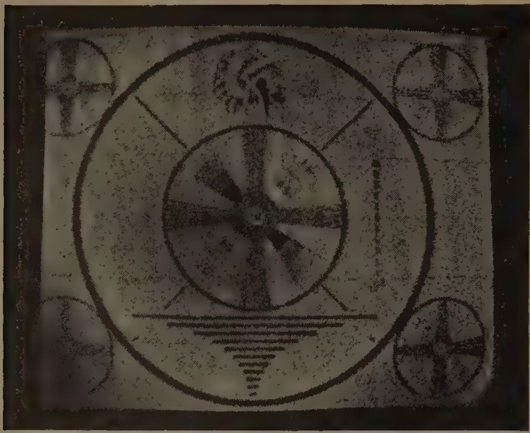


Fig. 13—Conventional receiver—hiss noise.

Fig. 14—Automatic frequency- and phase-controlled receiver—hiss noise.

noise. The loss of horizontal resolution and lack of interlace are plainly evident in Fig. 13. Resolution in Fig. 14 is limited only by the modulation of the kinescope by noise. This observation was made when a noise-free driven synchronizing signal was substituted but the picture signal left unchanged. Interlacing in Fig. 14 is not perceptibly affected by noise.

The interference in Figs. 15 and 16 was caused by an electric razor. Synchronization in Fig. 15 (conventional receiver) is lost entirely during severe noise peaks. Horizontal resolution is also seriously affected. Fig. 16, received on an automatic frequency- and phase-controlled receiver, does not exhibit the loss of resolution seen in Fig. 15.

The operating characteristics of an automatic frequency- and phase-controlled receiver and of a conventional receiver are quite different. During severe noise conditions a picture synchronized by automatic frequency and phase control remains together as a whole but may appear to move slightly about the equilibrium position in a random manner. Single lines or groups of lines cannot tear out horizontally because the filter in the horizontal circuit does not pass components of the control signal which would cause abrupt changes in oscillator speed. When synchronizing signals are obliterated for an appreciable length of time, the vertical and horizontal oscillators run at the free-running speed until synchronizing is re-established. When the receiver is properly adjusted, the free-running speeds are equal to or very close to the synchronous speeds, a condition which favors pull-in.

Automatic frequency- and phase-controlled synchronization is not entirely without disadvantages. For instance, reasonably good stability must exist in the synchronizing generator at the transmitter. However, the tentative standard recommended by the Federal Communications Commission is deemed entirely adequate and present synchronizing generators are well within the recommended standard. Also, since the system is slow to fall out of synchronism, it is likewise

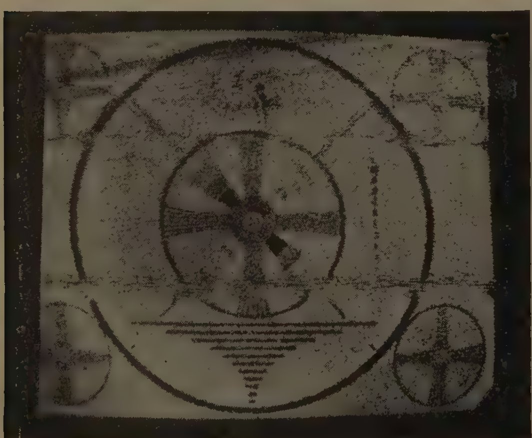


Fig. 15—Conventional receiver—interference from electric razor.

Fig. 16—Automatic frequency- and phase-controlled receiver—interference from electric razor.

slow to pull into synchronism. For instance, during a local thunderstorm, when a multiple lighting stroke obliterates the signal for a considerable portion of a second, the oscillators may fall out of synchronism and require as much as a second to resynchronize.

The system is sensitive to line-voltage variations unless glow-tube regulation is used. The regulated power required is small, however, and the chief objection is that occasioned by the extra tubes and sockets.

Conclusions

Superior reception resulting from the use of automatic frequency- and phase-controlled synchronizing has been experienced in field tests under conditions of severe noise such as may exist occasionally even within the normally useful service area of a television station. Horizontal resolution is found to be limited only by modulation of the kinescope by noise. Noise does not destroy interlacing of scanning lines. Tearing of the picture in horizontal strips and rapid vertical movement which may occur in a conventional receiver during severe noise bursts are essentially eliminated by the long time constants of an automatic frequency- and phase-controlled system.

Engine-Driven Emergency Power Plants*

KARL TROEGLEN†, MEMBER, I.R.E.

Summary—*This paper covers various factors involved in the selection, installation, and maintenance of a power plant used by radio station WIBW to furnish emergency power for its transmitting station.*

As THE importance of radio broadcasting increases in the everyday life of the American people, the need of increased reliability of this service also grows, if the listener and commercial interests are to be served properly. Failure of technical facilities affecting this reliability of service can generally be divided into two classes.

1. Those under the control of the station engineer.
   (a) Studio and transmitter equipment failure.
2. Those beyond the control of the station engineer.
   (a) Telephone-facilities failure.
   (b) Power-supply failure.

It is the power-supply problem with which we shall concern ourselves at this time. Until recently engine-driven power units were commercially available in wide variety. Since such machines are increasingly difficult to obtain now, it is of special interest to see what can be accomplished with a power-supply assembly made up of separately purchased components not necessarily designed for use together. The finished machine should have the following characteristics:

1. It should be able to furnish its full output continuously. The voltage and frequency stability should be sufficient, under moderate load variations, to avoid causing serious carrier shift.

2. It should be easy to start and capable of delivering full load in as short a time as possible so as to reduce carrier interruptions to a minimum.

3. It should be built from component parts that are in common use so that repairs to both motor and generator can be made more easily.

4. It should be as simply constructed as is possible.

5. It should offer a minimum of installation problems.

6. It should operate economically.

7. The price of the machine should be reasonable. Power interruptions in some areas are so infrequent it is difficult to justify a large expenditure.

While various types of machines are available, consideration of the above-named features indicates that only two types of engine-driven supplies have most of these characteristics.

1. Diesel-driven units
2. Gasoline or natural-gas-driven units.

The Diesel-driven machine has the advantage of slower speed and lower fuel consumption (in cost per kilowatt hour). However, it weighs considerably more than an ordinary gasoline engine for the same power delivered and offers some starting problems not encountered with a gasoline engine. The problem of maintenance and repair is also more complex in the case of the Diesel. The original cost of a gasoline-engine-driven machine is quite a bit lower than that of a Diesel. While the Diesel is more economical for continuous use, it is not so economical as the gasoline engine for use over short periods of time.

Thus the machine decided upon for our station consists of a general-purpose gasoline engine of reliable manufacture and a standard, well-known alternator with externally mounted exciter.

The six-cylinder engine, designed to deliver 82-brake horsepower at 1200 revolutions per minute, is equipped with a standard centrifugal governor for speed regulation. This governor has two movable weights which are attached to a gear connecting with the crankshaft. As the speed of the machine increases, these weights press against a bar which in turn moves the lever controlling the carburetor flipper valve. Thus by controlling the amount of gasoline entering the engine, the speed is held essentially constant. Experience indicates that this type of governor is not so

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rapid in action as the flyball type but is still satisfactory, as will be shown later. Starting is accomplished by a standard starter motor operated automatically by a Bendix Startix. A 12-volt starting and ignition system is used to facilitate easy starting; a Sisson electric choke is used in conjunction with the starting system. The engine is equipped with oil and air filters and a standard generator. A thermal cutout is provided which opens the starting circuit if repeated cranking does not start the machine and a backfire

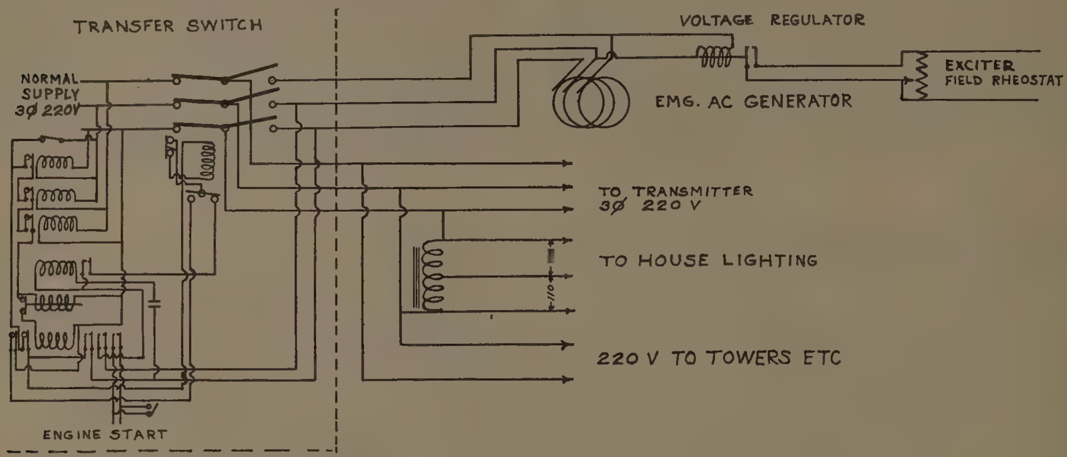

Fig. 1—Transfer switch and connections to generator and building wiring.

cutout is provided which opens the ignition circuit in case of engine backfire. The generator is rated at 37.5 kilovolt-amperes and will deliver 30 kilowatts at 0.80 power factor. This output is at 220 volts, 60 cycles, three phase in a three-wire circuit. A three-wire system is used in this installation for several reasons. First, the power to the building is brought in on three wires. Inside of the building, a 5-kilovolt-ampere autoformer across one phase is used to supply the 120-volt circuits. By using a three-wire system the automatic switch can be used to transfer from normal to auxiliary supply at the point where the power enters the building. A three-wire system is more economical to install. In some cases it might be better to install a four-wire system, in this way dispensing with the house transformer. The engine and generator are mounted on a welded-steel frame made of 10-inch channels. The over-all size of the machine is 103 inches long, 30 inches wide, and 67 inches high. The weight is about 4000 pounds. The engine and generator are coupled through a large double-flange type of coupling. A vibrator-type regulator is used to regulate the output voltage under varying load conditions. This type of regulator is inexpensive and seems to function very well in this service. A solenoid is energized from one of the three phases of the alternator. Inside of this solenoid is a floating core which serves to open and close a set of contacts, thereby alternately inserting and short-circuiting the exciter field rheostat. Since this is 60-cycle current, the regulator actually functions 120 times per second. Any change in alternator voltage is thus compensated for by the regulator. The total range over which this regulator will control the output voltage depends on the adjustment of the contacts. The automatic transfer switch is conventional in that it has full three-phase protection. The emergency supply is started when any one of the phases of the regular supply drops to 70 per cent of its normal value. Transfer is effected as soon as the voltage and frequency of the emergency supply reach predetermined values and is controlled by a tuned relay circuit. After the regular supply voltage has been restored to at least 90 per cent of normal on all three phases, return to the regular supply is delayed for a predetermined period by a time-delay relay. This is done to avoid outages due to the regular supply coming on for a few seconds and dropping out again. Switches are also provided to start the machine for test purposes and to permit connecting the load to the emergency supply even if the regular supply has not failed. The machine will start and connect itself to the load in from four to six seconds. The transfer back to the regular supply is so rapid that no carrier interruptions are apparent. A circuit diagram of the power supply and auxiliary alternating-current wiring is shown in Fig. 1.

In planning the installation of such a machine it is best to consult with the local Fire Inspection Bureau. While the National Fire Underwriters do have some regulations regarding the installation of such machines, the local rules take precedence. Generally speaking, the machine should be located in a well-lighted and well-ventilated room, preferably on the first floor. If the machine is to be mounted on a wood floor, the floor within 24 inches of the machine should be covered with some fireproof material. An overflow pipe from

the carburetor back to the fuel-supply tank should be provided. Exhaust pipes should be run so as not to present a fire hazard. Buried fuel tanks must be so buried that the top of the tank is at least 30 inches under ground and they must be properly ventilated. Fuel pipes should be at least of one-quarter inch inside diameter and of either wrought iron or copper. Where copper is used precautions must be taken to protect this pipe from mechanical damage.

In our case the machine was set up in a room especially intended for this purpose. It is 10 by 20 feet with a 10-foot ceiling height. The room is well lighted and can be ventilated when the machine is in operation. The machine, being equipped with a standard truck radiator, depends entirely on the surrounding air for its cooling. A gauge on this radiator shows that even after several hours of operation at ambient temperatures about the 100-degree mark, the water temperature did not go above 180 degrees Fahrenheit. The room is heated in winter to facilitate easy starting. The machine is set on a single layer of Keldur which serves as an efficient vibration deadener. Mounting bolts are insulated from the machine by Keldur bushings and washers. A 250-gallon tank buried just outside of this room serves as the fuel-supply container. The top of this tank is actually five feet below the gasoline pump on the engine but this has presented no problem as

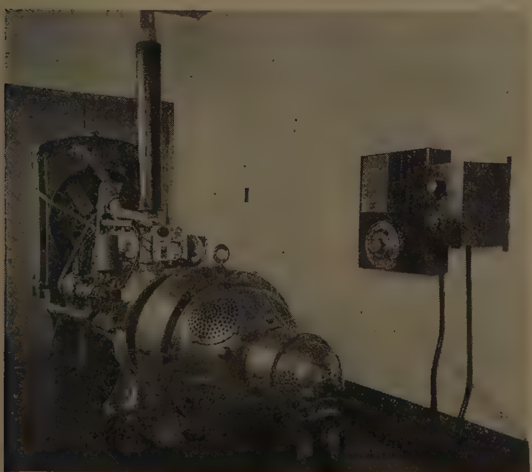

Fig. 2—Plant as installed with exciter field rheostat and voltage regulator mounted on wall next to battery charger.

the pump is well able to lift the gasoline this distance. As shown in Fig. 2, the muffler is mounted directly on the exhaust manifold. From this muffler a three-inch pipe about ten feet long leads to the outside to serve as an exhaust for the engine. To prevent this pipe from being a fire hazard it was led through the wall in the center of a foot-square hole. The space between the pipe and the wall was filled with the clay used to pack between bricks in a furnace firebox.

After installation it is necessary to adjust the engine speed and generator voltage to the desired operating conditions. While it is desirable to have a voltmeter and frequency meter as an integral part of this machine, experience showed that they were not necessary once the system was adjusted. The voltmeter, which

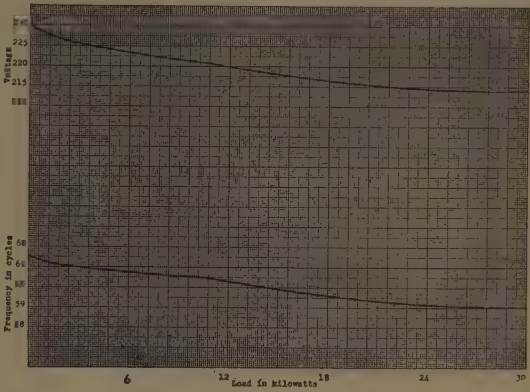

Fig. 3—Voltage and frequency change as plant load is increased from no load to full load.

is part of the transmitter proper, serves as a constant-voltage check. While the operating frequency can be checked in various ways, an oscilloscope was used in this case, the commercial supply being considered as normal 60-cycle current. Other methods which would also serve the purpose are:

1. Synchronous phonograph motor with stroboscope disk and a neon light operated from the commercial supply.
2. Two synchronous clocks, one connected to normal supply the other to the emergency supply.
3. Motor-speed indicator of the type used by motor-repair shops to check reconditioned motors.

The performance of this machine is indicated in Fig. 3. The voltage and frequency graphs were made under actual operating conditions by turning on the lighting, heating, and transmitter load in stages. The gradual decreasing of the output frequency is due to the slowing down of the gasoline engine. It can be seen that the voltage regulator becomes very effective after the machine is carrying approximately one half of its full load. Under operating conditions the output frequency was observed to hunt slightly, varying a quarter of a cycle above and below the operating value. This frequency shift is slow and irregular and hence is not shown on the graph. The frequency variation, however, was not noticeable when electrical transcriptions were played and when the turntable was run from this power source. Fig. 3 shows that from no load to full load the output frequency varied from 61.5 to 59 cycles. This is equal to an engine-speed variation of from 1230 to 1180 revolutions per minute. This regulation is sufficient for ordinary uses and

would present no problem to stations equipped with automatic voltage regulators on the transmitter input. Fuel consumption under full load is six gallons per hour.

Maintenance

The maintenance routine consists of regular inspection and cleaning. The starting battery is kept fully charged at all times. The machine is given an actual load running test weekly so as to operate the transfer switch and machine under service conditions.

Conclusions

That machines of this type will give satisfactory results in radio stations even for continuous service is evident from the fact that this machine has been in service for nearly three years. The transmitter is a Western Electric 355-E-1, 5-kilowatt unit, low-level-modulated, and it has only a water pump and fan as rotating components. No extreme voltage surges have ever occurred when part of the load was removed or rapidly applied. Under these conditions there is a voltage swing, but due to the inertia of the machine it is not very rapid. When operating under full load, the output voltage actually is more constant than that of our normal supply. There seems to be no need for either a frequency meter or speed indicator on the output of this machine. The speed adjustment was set when the machine was installed and has not had to be changed since that time. Care in selection should be exercised to insure that the machine is capable of handling the load with a generous reserve margin. Generally speaking the gasoline engine should be able to furnish from 2.5- to 3-brake horsepower per kilowatt of delivered output power. This is especially necessary where the load on the machine varies due to modulation of the broadcast transmitter.

Selected Problems in Architectural Acoustics*

M. RETTINGER†, NONMEMBER, I.R.E.

Summary—*The paper discusses a number of undesirable acoustic effects together with measures which have to be taken to avoid or ameliorate these conditions. The first problem discussed deals with the absorption of high-frequency sound in air, the change of high-frequency reverberation with relative humidity of the air in a specific enclosure, and the average surface absorptivity required in this room to provide constant reverberation time for frequencies above 1000 cycles. Noted also is the energy reduction of high-frequency sound with change in reverberation and the air attenuation of high-frequency sound as a function of distance. In another problem the effects of sound interference are pictured as a function of the distance between source of sound and the point of observation and attention is drawn to the interference-reducing effect of surfaces not too highly reflective. After a comparison between "optic" and "acoustic diffusers," there is cited and pictured graphically the (Rayleigh) solution to the problem of the interference effect produced by a wall of sinusoidal cross section.*

IT IS the purpose of this paper to consider in some detail a number of problems in acoustics pertaining to recording studios and the conditions of microphone pickup. A case deserving attention, particularly in the recording of music, is the absorption of high-frequency sound in air and the change of reverberation time of these higher registers with a change in the relative humidity of the air. Fig. 1 (after Knudsen[1,2]) shows the absorption of sound in air for various frequencies as a function of relative humidity, while Fig. 2 shows the (extrapolated) absorption characteristic for various degrees of relative humidity. In order to obtain an illustrative picture of the degree in which high-frequency sound is absorbed in a room, let us consider a scoring stage of 100,000 cubic feet volume having a reverberation time of 1 second at 1000 cycles. This means, working with the "Sabine reverberation-time formula," that the total absorption of sound in the room at 1000 cycles comes to

$$A = \frac{0.05V}{T}$$

$$= \frac{0.05 \times 100{,}000}{1}$$

$$= 5000 \text{ sabines}$$

where A = total absorption units (sabines)
T = reverberation time (seconds)
V = volume (cubic feet).

Let us further assume that by some means it became possible to keep this total (surface) absorption constant for all frequencies above 1000 cycles. Fig. 3 depicts the reverberation characteristic of this room when the absorptivity of the air is taken into consideration according to

$$T\,\frac{0.05V}{[A+4mV]}$$

where m represents the absorptivity of air as shown on Figs. 1 and 2. It is seen that the reverberation time for the higher registers is rather short, even at the relative humidities of 40 and 50 per cent.

The question naturally arises now what the average absorptivity characteristic of the wall surfaces would have to be if a constant reverberation time of 1

* Decimal classification: 534. Original manuscript received by the Institute, July 21, 1941; revised manuscript received, November 4, 1942.

† RCA Manufacturing Co., Hollywood, California.

[1] V. O. Knudsen, "The effect of humidity upon the absorption of sound in a room, and a determination of the coefficient of absorption of sound in air," *Jour. Acous. Soc. Amer.*, vol. 3, p. 120; July, 1931.

[2] V. O. Knudsen, "Absorption of sound in air, in oxygen, and in nitrogen effects of humidity and temperature," *Jour. Acous. Soc. Amer.*, vol. 5, p. 112; October, 1933.

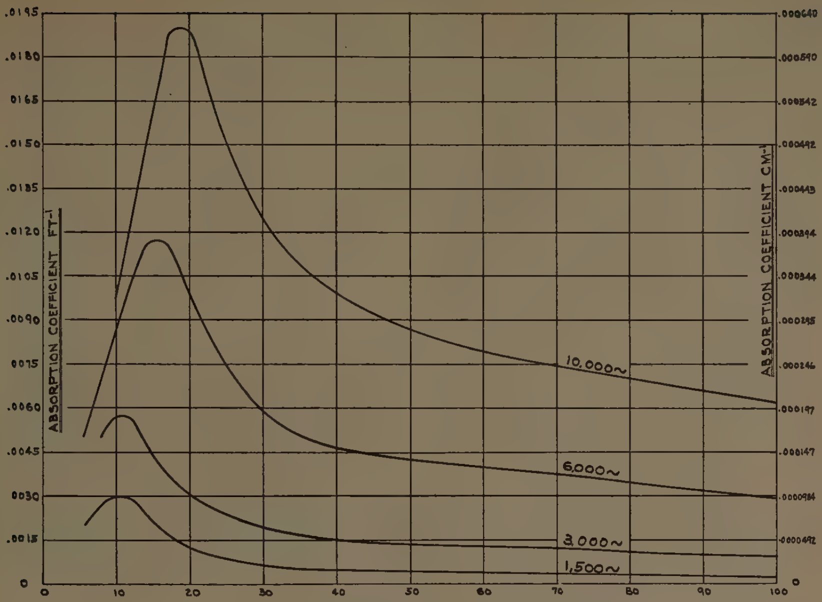

Fig. 1—Absorption of sound in air at 20 degrees centigrade (68 degrees Fahrenheit) and relative humidities shown on the X axis.

second were desired in the room. For this purpose let us assume that the ratio of dimension for the height, width, and length of the enclosure of 100,000 cubic feet corresponds to the oft-quoted ratio of 2:3:5, so that the total interior surface will come closely to 14,000 square feet. Fig. 4 represents, for various per cent relative humidities, the absorptivity characteristic of the wall material required to secure a constant reverberation time of 1 second for all frequencies above 1000 cycles. This figure shows that at low relative humidities it is impossible to secure this condition of constant reverberation time, while for higher relative humidities some effort may have to be exerted to devise an acoustic treatment exhibiting the decreased absorptivity called for on Fig. 4. The question as to the most desirable reverberation characteristic in

Fig. 2—Absorption characteristic of sound in air for various degrees of relative humidity.

recording studios has been widely discussed in the literature, with the result that a number of criteria for this characteristic are available. In this connection the

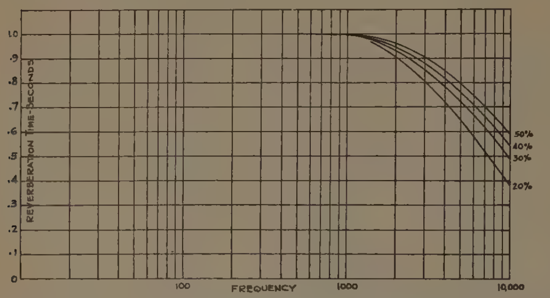

Fig. 3—Variation of reverberation time with frequency in a room of 100,000 cubic feet volume at 20 degrees centigrade and various per cent relative humidities, assuming constant boundary absorption (5000 sabines) above 1000 cycles.

reader is also referred to a recent article by the author dealing at some length with this subject.[8]

Fig. 5 shows the reverberation characteristic of a scoring stage recently completed in Hollywood as measured with a high-speed level recorder while the relative humidity in the stage was 40 per cent. The high absorption required in the stage for the frequencies below 1000 cycles was achieved not so much by means of one particular acoustic material as by means of an acoustic treatment for which conversion of sound energy into heat through the frictional resistance of the pores of the wall surfaces was small. Porous materials are notoriously high absorbers of high-frequency

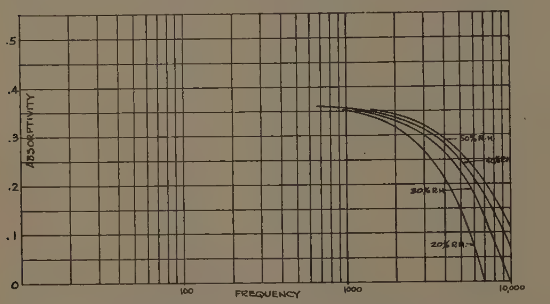

Fig. 4—Average absorptivity required of boundary material in a room of 100,000 cubic feet volume and 14,000 square feet interior surface at 20 degrees centigrade and various per cent relative humidities to secure constant reverberation of 1 second.

sound while frequently their low-frequency absorption is comparatively small. The acoustic treatment employed in this particular stage consisted of variously sized panels of oil-painted high-density fiberboard nailed to studs and backed by rockwool which exerted a damping action. Such a treatment provides decreasing absorption with increasing frequency, which is the condition previously specified for constant reverberation time above 1000 cycles.

[8] M. Rettinger, "A modern music recording studio," *Jour. Soc. Mot. Pic. Eng*, vol. 39, p. 186; September, 1942.

The lowering of the reverberation time brought about by a change in the relative humidity is accompanied by a sound-energy reduction within the enclosure. The sound-energy reduction is given by

$$\text{db} = 10 \log \frac{T_1}{T_2}$$

where T_1 is the reverberation time at a relative humidity RH_1 and T_2 the reverberation time at a relative humidity RH_2.

In this connection it may be of interest to note the reduction in sound energy due to air absorption for the higher registers as a function of distance. Fig. 6 shows this relationship graphically, and it is seen that this sound-energy reduction is rather large even at moderate distances from the sources. This condition points clearly to the desirability of employing, particularly in the recording of music where the microphone distance may be large, a recording characteristic in which the high frequencies are considerably amplified.

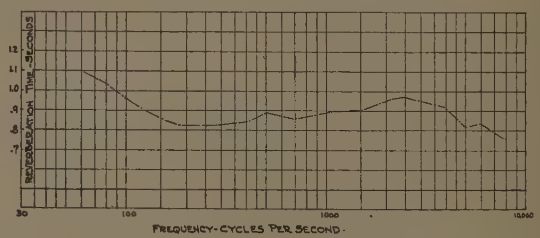

Fig. 5—Reverberation of Hollywood scoring stage as measured with a high-speed level recorder.

It should be noted that the amounts of attenuation shown on Fig. 6 are those due entirely to the absorption of sound in air. These amounts were calculated as follows (assuming an inverse square field, as in the open):

Let $I_2 = I_1 \exp[-m(d_2 - d_1)]$

where I_1 = intensity of sound at distance d_1

I_2 = intensity of sound at distance d_2

m = absorption of sound in air (values of Fig. 1).

The attenuation, therefore, comes to

$$\text{db} = 10 \log I_2/I_1 = 10 \log \exp[-m(d_2 - d_1)]$$

$$= -4.3m(d_2 - d_1).$$

The total decrease in sound level as the point of observation is moved from d_1 to d_2 is given by

$$-\text{db} = 20 \log d_2/d_1 + 4.3m(d_2 - d_1).$$

Another undesirable acoustic effect which deserves some scrutiny in connection with the recording of sound is that produced by interference. It is well

known that when the path difference between a reflection and the direct sound "ray" amounts to a wavelength or a multiple thereof, sound reinforcement takes place, while when this path difference comes to a half wavelength or an odd multiple thereof cancellation or destructive interference occurs. As the frequency spectrum is traversed, there occurs at a point of observation a series of sound pressure (or particle velocity) maxima and minima as shown on Fig. 7. If we move the microphone to a greater distance, similar maxima

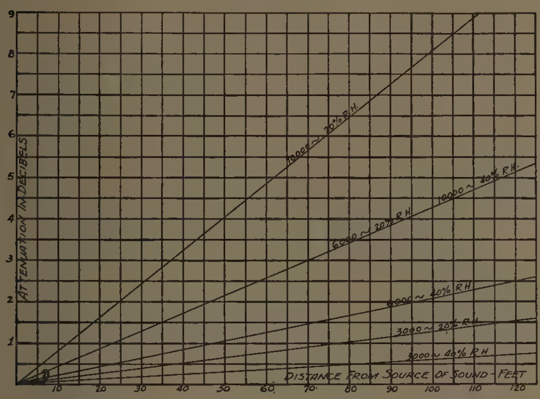

Fig. 6—Attenuation of sound due to absorption in air at 70 degrees Fahrenheit and relative humidities indicated on curves.

and minima occur which may be shifted along the frequency axis. The point to notice, however, is not the displacement of these partial nodes and antinodes along the frequency scale, but their change in value. The greater the microphone distance the more violent do these "peaks" and "dips" become. It may be of interest to note the change in magnitude of these interference maxima and minima as the point of observation moves farther away from the source. Fig. 8 depicts this relationship graphically. It is seen that a wall material with even relatively small absorptivity can markedly reduce this interference effect. This points to the inadvisability of employing large hard surfaces

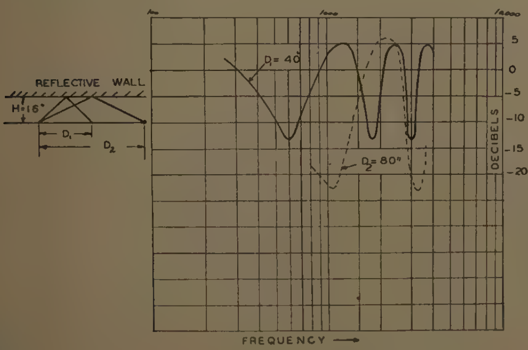

Fig. 7—Pressure interference maxima and minima produced by reflections from a reflective wall.

which are flat in a recording studio where the microphone distances employed are large. It may also prove advisable to use some covering on the floor, as this surface is usually the most likely to offend in this respect.

While the sound-pressure interference effects can

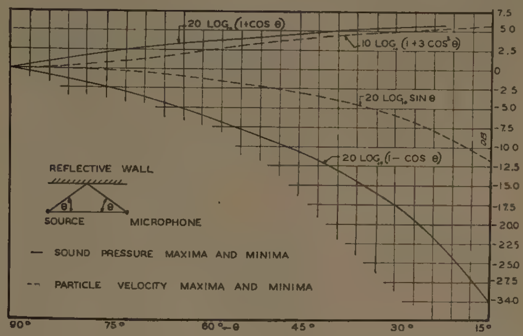

Fig. 8—Magnitude of sound pressure and particle velocity interference maxima and minima as a function of the angle θ.

readily be measured with a pressure microphone, care must be exercised when a velocity microphone is used. To obtain the absolute value of the particle velocity in an interference field it is necessary to take three independent readings with the velocity microphone being oriented along mutually perpendicular axes and then to take the vectorial sum of these readings.[4]

Rooms in which the acoustics of the enclosure is given marked consideration are often designed to have the wall surfaces well broken up, either in the form of pilasters, pillars, niches, etc., or by making the con-

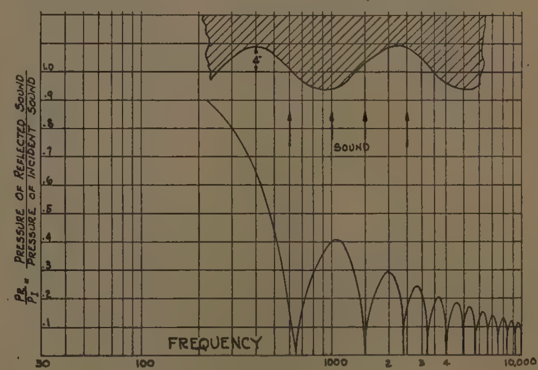

Fig. 9—Sound-reflection characteristic from a rigid nonporous wall of sinusoidal contour.

tour of the entire wall itself more or less irregular. The chief benefit of such irregularities of wall surface lies in the reduction and even complete elimination of the echo effect (at least as far as the ear is concerned). No examination shall be made here as to the ineffectual use of such irregularities in altering the number of

[4] H. F. Olson and F. Massa, "Applied Acoustics," second edition, P. Blakiston's Sons and Co., Philadelphia, Pennsylvania, p. 311.

room resonances or eigentones in an enclosure of given volume.[5]

In evaluating the dispersing or diffusing effect of irregularly shaped wall surfaces it may be advisable to consider more closely the term diffuser or diffuse reflector. In optics a diffuse reflector is one which obeys Lambert's cosine law; that is $I = I_0 \cos\theta$, where θ is the angle between the normal to the surface and the given direction, and I_0 the intensity along the normal. It should be appreciated here that in the case of good light diffusers, such as freshly fallen snow for instance, a great deal of the light which penetrates the material to a considerable extent and suffers numerous reflections in its transit is eventually reflected back into the original medium. This is hardly possible in the case of sound, however, where a large portion of the incident energy is absorbed (changed into heat) if it enters the material. Nongeometric reflection of sound is therefore primarily dependent on surface irregularities and only secondarily on internal scattering.[6] For this reason the linear dimensions of wall irregularities must represent several wavelengths before it can be hoped to secure diffuse reflections of sound from such a wall. If this is not the case, if the irregularities are of the order of half a wavelength or even smaller, the wall will act in the first instance more like an acoustical mirror permitting mainly of specular reflections.

Rayleigh[7] investigated the case of sound reflection from a wall whose cross-sectional profile is that of a sine wave (see Fig. 9). The assumptions made are that the point of observation is considerably removed from the wall and that the sound is not permitted to penetrate the material to any great depth. Penetration of sound into the material will bring about not only a change in the amplitude of the peaks shown on the figure, but will also effect a shift of the peaks along the frequency axis. The equation[8] for the curve shown is

$$\frac{P_R}{P_X} = J_0(2kA)$$

where J_0 = Bessel function of zeroth order

$$k = \frac{2\pi F}{c}$$

c = velocity of sound
F = frequency
A = amplitude of the sine wave of profile.

A wall of this contour acts in the same manner as a Rowland grating in optics and produces acoustic spectral lines of the n^{th} order corresponding to path differences of rX.

From the foregoing we should appreciate the fact that wall irregularities, no matter how complex, can not eliminate interference of sound in a room. They are able, however, to eliminate echoes, and to effect some dispersion of sound, especially when they are convex.

[5] The reader is referred to recent issues of the *Journal of the Acoustical Society of America.*
[6] E. Skudrzyk, "Über die Eigentöne von Räumen mit nichtebenenen Wänden und die diffuse Schallreflexion," *Akust. Zeit.*, vol. 4, p. 172; May, 1939.
[7] Lord Rayleigh, "Theory of Sound," Macmillan and Co., Ltd., London, England, vol. II, p. 272a.
[8] $Jo(x)$, for large values of x, is given approximately by $\sqrt{2/\pi x}\cos(x-\pi/2)$.

A Frequency-Modulated Resistance-Capitance Oscillator*

C.-K. CHANG†, NONMEMBER, I.R.E.

Summary—*A method of producing frequency-modulated waves is described in which a resistance element in a resistance-capacitance-tuned oscillator is replaced by the output resistance of a variable-μ tube. As the grid potential of the latter tube is varied, its output resistance varies, and a wide-band frequency modulation of the oscillator is obtained. Mathematical relations between the frequency variation and the grid-potential change are derived. Experimental results are discussed.*

Introduction

Among the present methods of obtaining frequency modulation, the most successful have been the Armstrong method and the reactance-tube method. This paper describes a simple, alternative method which gives wide frequency deviation directly.

A resistance-capacitance-tuned oscillator, as shown in Fig. 1, is employed. The frequency of oscillation is given by the expression[1]

$$f = \frac{1}{2\pi\sqrt{C_1C_2R_1R_2}}. \tag{1}$$

This shows that the frequency may be varied by varying R_1 or R_2. Let R_1 or R_2 consist of the plate resistance of a vacuum tube. If the grid voltage of this tube (which we shall call the resistance tube) is varied, its plate resistance will vary, and the frequency of the oscillator will change accordingly. If the grid voltage

* Decimal classification: R355.9×R414. Original manuscript received by the Institute, April 20, 1942; revised manuscript received, September 29, 1942.
† Stanford University, California.

[1] F. E. Terman, R. R. Buss, W. R. Hewlett, and F. C. Cahill, "Some applications of negative feedback with particular reference to laboratory equipment," Proc. I. R. E., vol. 27, pp. 649–655; October, 1939.

is varied at an audio rate, frequency modulation will result.

Ordinary triodes or pentodes are not suitable as resistance tubes when the oscillator frequency is of the order of several megacycles, because of their high plate resistance. However, by means of the cathode-follower circuit, there may be obtained a resistance of a low value which is equal[2] to

$$R = \frac{1}{G_m + \dfrac{1}{R_c}}, \tag{2}$$

where G_m is the transconductance of the tube and R_c is the cathode resistor.

The complete frequency-modulated oscillator circuit is shown in Fig. 2. Here, the resistance tube (T) is preferably a variable-μ tube. This type of tube allows greater variation of G_m with grid voltage than other types of tubes. L_1 and L_2 are high-frequency compensating coils which will be explained later.

Mathematical Analysis

Let us now proceed to find a quantitative relation between the frequency of the oscillator and the change of grid potential of the resistance tube. The frequency of oscillation is repeated below:

$$f = \frac{1}{2\pi\sqrt{C_1C_2R_1R_2}}.$$

If R_2 is replaced by the output resistance of the resistance tube, then, by substituting R of (2) for R_2 and writing

$$\frac{1}{2\pi\sqrt{C_1C_2R_1}} = a,$$

we have

$$f = a\sqrt{G_m + \frac{1}{R_c}}. \tag{3}$$

For simplicity, assume that R_c is large enough so that (G_m+1/R_c) is approximately equal to G_m; then (3) can be written

$$f = a\sqrt{G_m}. \tag{4}$$

For further simplification, suppose that the plate voltage of the resistance tube is high enough to cause the plate to receive most of the space current. Then for the plate current we can write

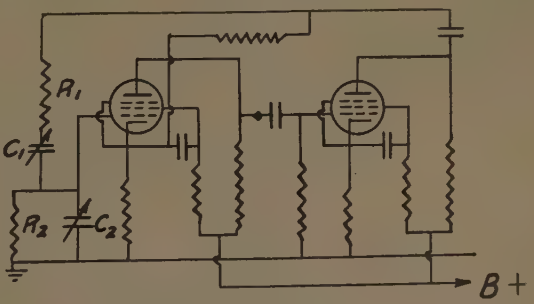

Fig. 1.—Typical circuit of a resistance-capacitance-tuned oscillator.

$$I_p = k(E_g + E_{sg}/\mu_{sg})^{3/2}.$$

Now suppose that the value of μ_{sg} remains essentially constant where E_g varies (this will be true if E_g does not go highly negative). Then

$$G_m = \frac{\partial I_p}{\partial E_g} = \frac{\partial}{\partial E_g}\left[k(E_g + E_{sg}/\mu_{sg})^{3/2}\right]$$
$$= \tfrac{3}{2}k(E_g + E_{sg}/\mu_{sg})^{1/2}.$$

Substituting this into (4) we have

$$f = a(\tfrac{3}{2}k)^{1/2}(E_g + E_{sg}/\mu_{sg})^{1/4}. \tag{5}$$

The frequency deviation with respect to the grid potential is then

$$\frac{\partial f}{\partial E_g} = \frac{a}{4}\left(\frac{3k}{2}\right)^{1/2}(E_g + E_{sg}/\mu_{sg})^{-3/4}. \tag{6}$$

If both R_1 and R_2 of the tank circuit of the oscillator consist of resistance tubes, better frequency deviation is obtained. For this case, equation (3) has the form

[2] A. A. Barco, "An iconoscope pre-amplifier," *RCA Rev.*, vol. 4, pp. 89–107; July, 1939.

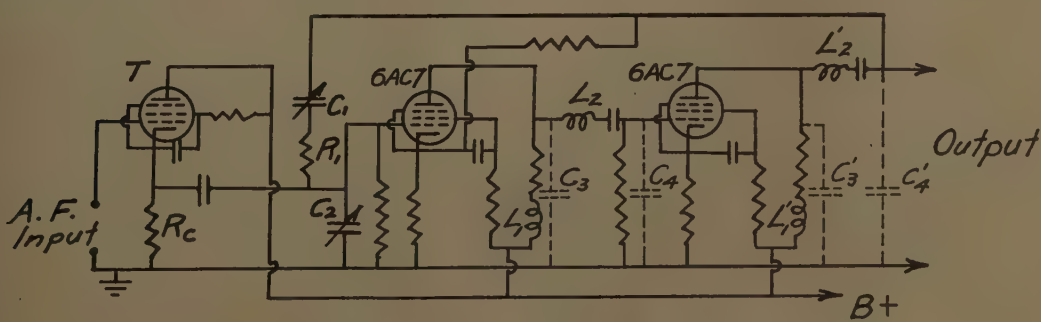

Fig. 2.—Circuit diagram of a frequency-modulated resistance-capacitance oscillator.

$$f = \frac{b}{\dfrac{1}{G_m + \dfrac{1}{R_c}}} = b\left(G_m + \frac{1}{R_c}\right), \tag{7}$$

where

$$b = \frac{1}{2\pi\sqrt{C_1C_2}} \cdot$$

Equation (4) becomes

$$f = bG_m, \tag{8}$$

and (5) becomes

$$f = \tfrac{3}{2}bk(E_g + E_{sg}/\mu_{sg})^{1/2}. \tag{9}$$

The rate of change of frequency with respect to grid voltage is then

$$\frac{\partial f}{\partial E_g} = \tfrac{3}{4}bk(E_g + E_{sg}/\mu_{sg})^{-1/2}. \tag{10}$$

These formulas apply to triodes if E_p and μ are used in place of E_{sg} and μ_{sg}, respectively.

The above results may be summarized as follows: When two resistance tubes are used in the oscillating circuit, the frequency of oscillation is directly proportional to the transconductance of the tubes, or to the square root of the quantity (E_g+E_{sg}/μ_{sg}); the frequency deviation with respect to the grid voltage is inversely proportional to the square root of the same quantity. If one resistance tube is used the frequency of oscillation will be directly proportional to the square root of the transconductance of the tube, or to the fourth root of the quantity (E_g+E_{sg}/μ_{sg}); the frequency deviation with respect to the grid voltage is inversely proportional to the three-fourths root of the same quantity

It is seen that when two resistance tubes are used we can obtain greater frequency deviation than when only one tube is used, but the circuit arrangement involved is rather complicated. It requires two sets of power supplies and is inconvenient. As it has been found experimentally that the frequency deviation obtained with one tube is more than actually used in practice, the circuit arrangement of Fig. 2 is preferred.

High-Frequency Compensation

The oscillator works well up to four megacycles if television tubes are used. To work at higher frequencies, a compensating device must be provided. In order to obtain best results both shunt and series peaking compensation must be used.[8] The shunt peaking coil L_1 (see Fig. 2) should have an inductance equal to $0.12(C_3+C_4)R_L^2$, and the series peaking coil L_2 should have an inductance equal to $0.52(C_3+C_4)R_L^2$ where C_3 and C_4 are the stray capacitances indicated in Fig. 2, and R_L is determined from C_3 and C_4, as will be shown later. The design procedure is as follows: first, decide upon the frequency of oscillation f_0; second, measure C_3 and C_4 for each tube of the oscillator circuit by finding the frequency f at which the amplification falls to 70.7 per cent of its mid-range value and then calculating C_3+C_4 from the relation $f=1/2\pi R_L'(C_3+C_4)$; next, determine the value of R_L which is given by the expression $R_L=f_0/2\pi R_L'(C_3+C_4)$; and then evaluate L_1 and L_2 from the foregoing equations.

When the combined shunt-series peaking is employed the oscillator can be made to operate at 9 megacycles. It has been found that there is no difficulty in obtaining oscillation at even higher frequencies.

Amplitude-Limiting Device

Finally, let us consider the amplitude variation of the output voltage of the oscillator during modulation. It is by no means constant, for the audio-frequency voltage due to the audio-frequency current flowing in the output of the resistance tube is applied directly to the input of the oscillator. This voltage will be amplified and cause the output voltage of the oscillator to vary at an audio rate, which is undesirable. In order to remedy the defect, a limiter may be connected to the output of the oscillator. It can be either a diode or a pentode type. If the former is used we should first estimate the value of $E_{\min}$ to which the oscillator voltage swings when it is modulated and then set the bias on the diode exactly equal to or a little less than this value. If a pentode is used, it may conveniently be of the plate-saturation type. By means of this arrangement the output power can be maintained practically constant over a grid-excitation voltage range of more then one hundred to one.

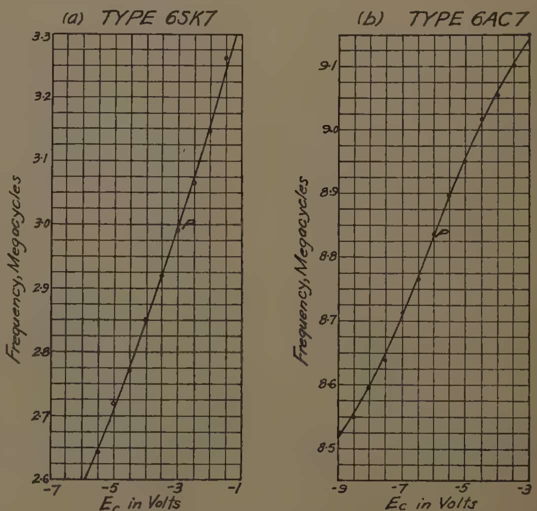

Fig. 3.—Oscillator frequency as a function of grid voltage of the resistance tube. Note that E_c is the battery bias only.

[8] D. G. Fink, "Principles of Television Engineering," McGraw-Hill Book Co., New York, N. Y., 1940, ch. 6.

Experimental Results

The frequency-modulated oscillator just described has been tested experimentally and satisfactory results were obtained.

In order to measure the frequency variation of the oscillator against the grid-voltage change of the resistance tube, an adjustable bias was connected to the input terminals of the latter (see Fig. 2), the audio-frequency source being disconnected at the time. Several types of tubes have been tested in this way and sample results for two tubes are plotted in Fig. 3.

From these curves it is seen that the oscillator frequency varies considerably with the grid voltage of the resistance tube. At the point P, a frequency change of more than 0.1 megacycle is obtained per volt change of grid voltage. This may seem astonishing at first sight, but if we look at the average characteristics of the tubes we note that the transconductance of the 6SK7 tube will increase from 1150 to 2250 micromhos as its grid voltage varies from -6 to -2 volts, and the transconductance of the 6AC7 tube increases from 1500 to 6000 micromhos[4] as its grid voltage varies from -8 to -4 volts. Since the frequency of oscillation is a function of the transconductance of the tube (as is shown roughly by the relation $f = a\sqrt{G_m}$), the results obtained above are reasonable.

The linearity of these frequency variation curves is comparable to that of the average characteristics of the tubes. If the operating point is suitably chosen (say, at P, Fig. 3), the 6SK7 tube gives a frequency deviation of the order of 16 kilocycles in 3 megacycles with less than 0.5 per cent distortion, while the 6AC7 tube gives a deviation of the order of 25 kilocycles in 8.8 megacycles with the same distortion.

Acknowledgment

The writer is greatly indebted to Professors F. E. Terman and K. Spangenberg and Messrs. S. W. Athey and H. J. Shaw for their valuable suggestions and helpful discussions during the course of this work.

[4] It should be remarked that these values are for $E_p = 300$ volts and $E_{sg} = 150$ volts; in our case the values of E_p and E_{sg} used were 240 and 120 volts, respectively, and hence a smaller variation of the transconductance of the tube is to be expected.

Comparison of Voltage- and Current-Feedback Amplifiers*

E. H. SCHULZ,† ASSOCIATE, I.R.E.

Summary—*This paper points out the differences between an amplifier with voltage feedback and one with current feedback. The effect of variations of amplifier constants on output voltage and current is decreased by either type of negative feedback. Voltage feedback decreases the effect of load impedance on output voltage, and current feedback decreases the effect of load impedance on load current. Voltage feedback increases the damping of a loudspeaker and improves its response. A table also is given to assist in the choice of type and amount of feedback to be used in a given application.*

Introduction

The operating characteristics of an amplifier may be improved considerably by the use of negative feedback. When a large part of the output voltage is fed back to the input so as to oppose the impressed voltage, the gain of the amplifier becomes essentially independent of operating voltages, tube constants, etc., and distortion, noise, and hum are materially reduced.

The method of obtaining the feedback voltage may have an appreciable effect on the characteristics of the amplifier. The various methods of obtaining feedback may be separated into two groups; namely, voltage and current feedback. In voltage feedback the feedback voltage is proportional to the output voltage, while in current feedback the feedback voltage is proportional to the output current. The term "feedback" will imply negative feedback throughout this paper.

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† Illinois Institute of Technology, Chicago, Illinois.

Symbols

- α = vector gain of amplifier without feedback
- β = vector feedback factor
- μ = vector amplification factor = μ of output stage $\times$ vector gain of previous stages
- E = equivalent vector internal generated voltage
- Z = vector impedance of amplifier looking into output terminals when feedback is used
- Z_i = vector impedance of amplifier looking into output terminals when no feedback is used
- Z_0 = vector load impedance
- θ_α = angle of phase shift through amplifier without feedback
- θ_β = phase angle of β
- θ_μ = phase angle of μ
- θ_0 = phase angle of Z_0
- θ_i = phase angle of Z_i
- ϕ = factor by which α must be increased to obtain same output as with no feedback.

Equivalent Circuits of Amplifiers with Feedback

Figs. 1 and 2 show the circuits of an amplifier with voltage feedback and one with current feedback. The

equivalent circuits shown in Figs. 1 (c) and 2 (c) are obtained by Thevenin's theorem. The magnitude of the generator voltage E is equal to the value of V_0 obtained when the amplifier is operating with no load (i.e., $Z_0=\infty$). The value of Z is equal to the impedance looking back into the output terminals with all inter-

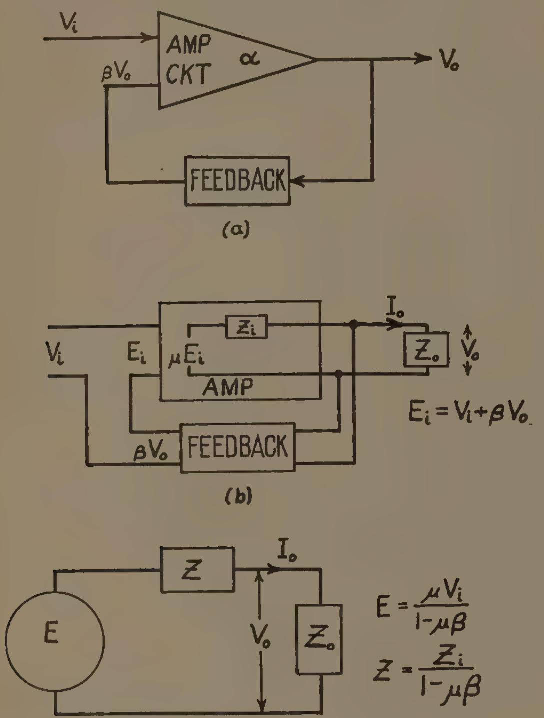

Fig. 1

nal voltages equal to zero (i.e., $V_i=0$). For example, to obtain E in Fig. 1 (c), the circuit of Fig. 1 (b) may be solved to obtain

$$V_0 = \frac{\mu Z_0 E_i}{Z_0 + Z_i} \tag{1}$$

where

$$E_i = V_i + \beta V_0. \tag{2}$$

Solving (1) and (2) for V_0,

$$V_0 = \frac{\mu Z_0 Z_i}{Z_0(1-\mu\beta) + Z_i}. \tag{3}$$

If $Z_0=\infty$,

$$E = V_0 = \frac{\mu V_i}{1-\mu\beta}. \tag{4}$$

To find the value of Z, let $V_1=0$, replace Z_0 by a source of voltage V_0, and calculate I_0 as follows:

$$I_0 = \frac{\mu E_i + V_0}{Z_i}. \tag{5}$$

But $E_i=0+\mu\beta V_0$ (since $V_i=0$) and hence

$$I_0 = \frac{\mu\beta V_0 + V_0}{Z_i}. \tag{6}$$

The impedance of the amplifier looking into the output terminals will be V_0/I_0. Hence

$$Z = \frac{Z_i}{1-\mu\beta}. \tag{7}$$

A similar process may be followed in the case of current feedback to arrive at the results of Fig. 2 (a).

Characteristics of Feedback Amplifiers

An inspection of Figs. 1 (c) and 2 (c) shows that voltage feedback increases the value of E above its value without feedback, while current feedback has no effect on the magnitude[1] of E. Also it may be seen that voltage feedback decreases the impedance looking back into the amplifier, while current feedback increases this impedance.

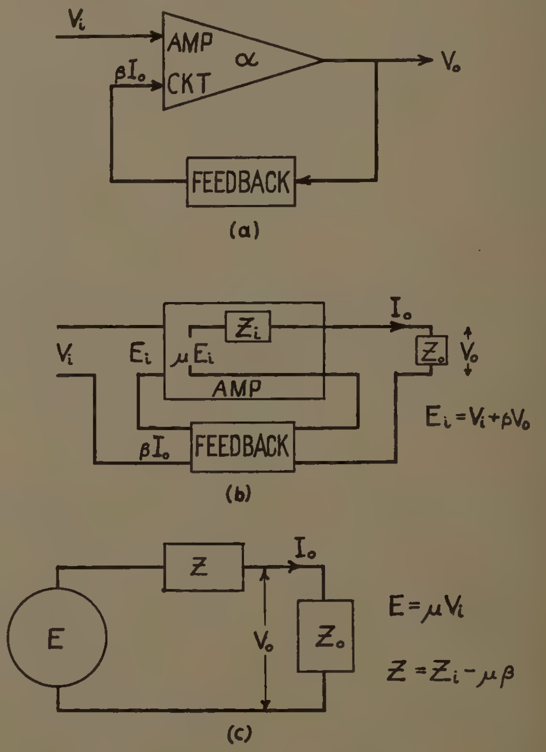

Fig. 2

From the above it follows that in an amplifier feeding a loudspeaker, voltage feedback results in a lower effective impedance shunting the loudspeaker, whereas current feedback would increase this impedance.

[1] In order to obtain negative feedback $\theta_\mu+\theta_\beta$ must be less than 270 degrees but greater than 90 degrees and hence $|(1-\mu\beta)|>1$.

TABLE I

CHARACTERISTICS OF AMPLIFIERS WITH FEEDBACK

	No Feedback	Voltage Feedback	Current Feedback
1. Voltage gain $=\frac{V_0}{V_i}$	$\frac{\mu Z_0}{Z_0+Z_i}$	$\frac{\mu Z_0}{Z_0(1-\mu\beta)+Z_i}$	$\frac{\mu Z_0}{Z_0+Z_i-\mu\beta}$
		$\frac{\alpha}{1-\alpha\beta}$	$\frac{\alpha}{1-\frac{\alpha\beta}{Z_0}}$
2. Phase angle between V_0 and V_i	$\theta_\alpha=\theta_\mu+\theta_0-\tan^{-1}\left[\frac{Z_0\sin\theta_0+Z_i\sin\theta_i}{Z_0\cos\theta_0+Z_i\cos\theta_i}\right]$	$\theta_\alpha-\tan^{-1}\left[\frac{-\lvert\alpha\beta\rvert\sin(\theta_\beta+\theta_\alpha)}{1-\lvert\alpha\beta\rvert\cos(\theta_\beta+\theta_\alpha)}\right]$	$\theta_\alpha-\tan^{-1}\left[\frac{-\left\lvert\frac{\alpha\beta}{Z_0}\right\rvert\sin(\theta_\beta+\theta_\alpha-\theta_0)}{1-\left\lvert\frac{\alpha\beta}{Z_0}\right\rvert\cos(\theta_\beta+\theta_\alpha-\theta_0)}\right]$
3. $\frac{\text{Output current}}{\text{Input voltage}}=\frac{I_0}{V_i}$	$\frac{\mu}{Z_0+Z_i}$	$\frac{\mu}{Z_0(1-\mu\beta)+Z_i}$	$\frac{\mu}{Z_0+Z_i-\mu\beta}$
4. ϕ	—	$1-\alpha\beta$	$1-\frac{\alpha\beta}{Z_0}$
5. $\frac{d}{dZ_0}\left(\frac{V_0}{V_i}\right)$	$\frac{\mu Z_i}{(Z_0+Z_i)^2}$	$\frac{\mu Z_i}{[(1-\mu\beta)Z_0+Z_i]^2}$	$\frac{\mu(Z_i-\mu\beta)}{[Z_0+Z_i-\mu\beta]^2}$
6. $\frac{d}{dZ_i}\left(\frac{V_0}{V_i}\right)$	$\frac{-\mu Z_0}{(Z_0+Z_i)^2}$	$\frac{-\mu Z_0}{[(1-\mu\beta)Z_0+Z_i]^2}$	$\frac{-\mu Z_0}{[Z_0+Z_i-\mu\beta]^2}$
7. $\frac{d}{d\mu}\left(\frac{V_0}{V_i}\right)$	$\frac{Z_0}{Z_0+Z_i}$	$\frac{Z_0^2+Z_0Z_i}{[(1-\mu\beta)Z_0+Z_i]^2}$	$\frac{Z_0^2+Z_0Z_i}{[Z_0+Z_i-\mu\beta]^2}$
8. $\frac{d}{dZ_0}\left(\frac{I_0}{V_i}\right)$	$\frac{-\mu}{(Z_0+Z_i)^2}$	$\frac{-\mu(1-\mu\beta)}{[(1-\mu\beta)Z_0+Z_i]^2}$	$\frac{-\mu}{[Z_0+Z_i-\mu\beta]^2}$
9. $\frac{d}{dZ_0}\left(\frac{I_0}{V_i}\right)$	$\frac{-\mu}{(Z_0+Z_i)^2}$	$\frac{-\mu}{[(1-\mu\beta)Z_0+Z_i]^2}$	$\frac{-\mu}{[Z_0+Z_i-\mu\beta]^2}$
10. $\frac{d}{d\mu}\left(\frac{I_0}{V_i}\right)$	$\frac{1}{Z_0+Z_i}$	$\frac{Z_0+Z_i}{[(1-\mu\beta)Z_0+Z_i]^2}$	$\frac{Z_0+Z_i}{[Z_0+Z_i-\mu\beta]^2}$
11. Noise voltage	N	$\frac{N}{1-\alpha\beta}$	$\frac{N}{1-\frac{\alpha\beta}{Z_0}}$

Hence, voltage feedback increases the speaker damping and improves the response, while current feedback decreases the damping and results in poorer response.

Item 1 of Table I shows that the gain of an amplifier is decreased by either type of feedback. Item 3 shows the factor by which α must be increased to obtain the same gain as without feedback. Item 11 shows that noise and hum are decreased by the same amount that the gain is decreased.

The signal-to-noise (or hum) ratio may be improved by applying feedback and by increasing the gain to compensate for loss of gain, provided the noise is not introduced in the input stage. If the noise is introduced at the input, the added gain will also amplify the noise, and hence the signal-to-noise ratio cannot be improved appreciably by feedback.

Items 6, 7, 9, and 10 show that the effect of changes of Z_i and μ on both voltage gain and output current is decreased in either type of feedback. Item 5 shows that the effect of changes of Z_0 on the voltage gain is decreased by voltage feedback, and increased by current feedback. Item 8 shows that the effect of changes of Z_0 on the output current is increased by voltage feedback, and decreased by current feedback. These points are illustrated by Figs. 3, 4, and 5.

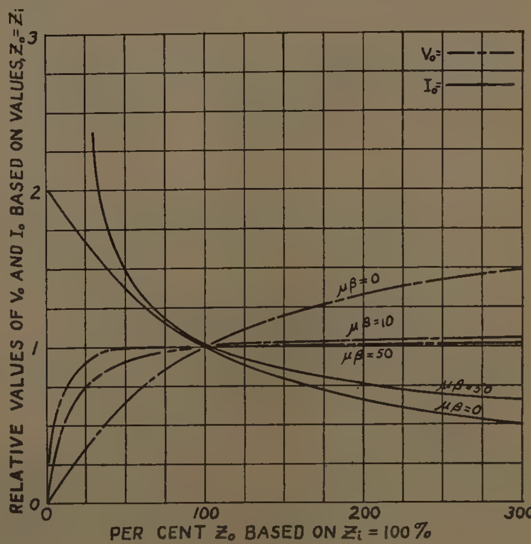

Fig. 3

CONCLUSIONS

Either type of feedback will decrease the effect of the constants of the amplifier on the voltage gain and

output current. That is, either type of feedback will have the following effects:

1. Reduce hum and tube noise.
2. Reduce variation of voltage or current gain with input voltage, operating voltages, tube age, etc.

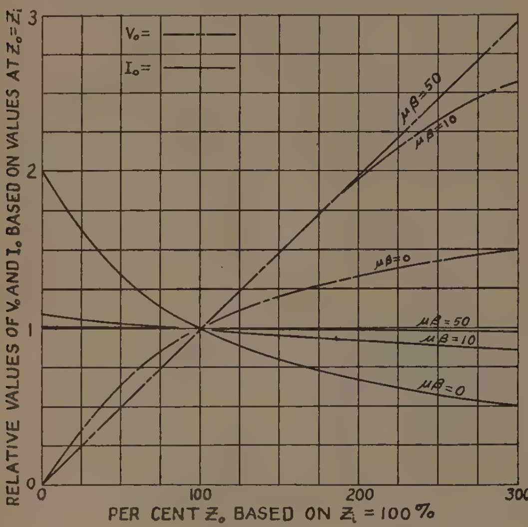

Fig. 4

Either type of feedback requires an increase in amplifier gain to obtain the same over-all gain as without feedback.

The difference in the behavior of amplifiers with voltage and current feedback is primarily in the effect of variations in the load on the output voltage and current. Voltage feedback will have the following effects:

1. Reduce the variation of voltage gain and phase angle of output voltage with load constants, but increase variations of output current and output-current phase angle with load constants.
2. Increase damping of loudspeaker transients and resonance, and hence improve speaker response.

Current feedback will have the following effects:

1. Reduce variations of load current and load-current phase angle with load constants, but increase variations of voltage gain and output-voltage phase angle with load constants.

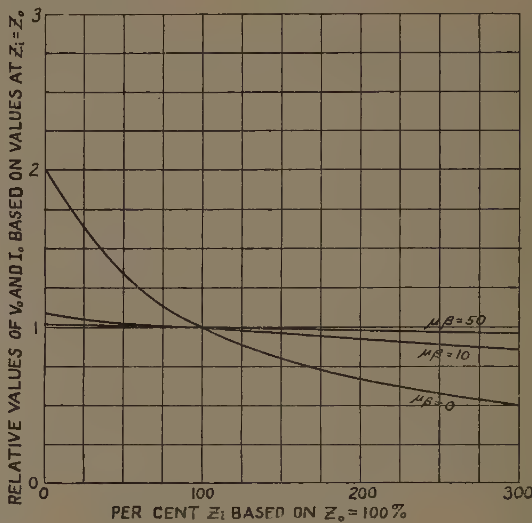

Fig. 5

2. Decrease damping of loudspeaker, and hence cause poorer speaker response.

References

1. H. S. Black, Stabilized feed-back amplifiers, *Elec. Eng.*, vol. 53, pp. 114–116; January, 1934.
2. H. J. Reich, "Theory and Application of Electron Tubes," McGraw-Hill Book Co., New York, N. Y., 1939, pp. 230–231.

Coupled Resonant Circuits for Transmitters*

N. I. KORMAN†, ASSOCIATE, I.R.E.

Summary—*This paper discusses the design of coupled resonant circuits for use as interstage coupling units in transmitters. Simplifying assumptions are made which, although they reduce somewhat the accuracy and scope of the treatment, result in extremely simple and useful relationships.*

Introduction

The subject of coupled resonant circuits has been treated many times in the various technical publications pertaining to radio. However, discussion with transmitter engineers has disclosed a certain amount of confusion on this subject. For instance, Terman[1] states that the condition for the flattest band-pass characteristic is the same as that for critical coupling, which is that the coupling $K=1/\sqrt{Q_1Q_2}$. A perfectly efficient interstage coupling unit for a transmitter will be one in which the inductances and capacitances will have no losses, and all of the damping is concentrated on the secondary side in the load. In this case, Q_1, the primary Q, is infinite (assuming also a constant current source of infinite internal impedance). Terman's formula for the coupling, which is strictly true only in the case where $Q_1=Q_2$, evidently is not

* Decimal classification: R142.3. Original manuscript received by the Institute, October 15, 1941; revised manuscript received, September 17, 1942.

† RCA Manufacturing Company, Inc., Camden, N. J.

[1] F. E. Terman, "Radio Engineering," Second Edition, McGraw-Hill Book Co., New York, N. Y., 1937, pp. 78–84.

applicable. Furthermore, for a transmitter engineer the coupling is an inconvenient quantity to design and to measure. It is preferable to design in terms of such things as voltage ratios, capacitances, and reactive powers.

Band-Pass—Low-Pass Analogy

In the discussion of the transmission characteristics of coupled resonant circuits, a considerable simplification may be obtained by the use of the band-pass—low-pass analogy. This analogy is a concept which has been recognized in certain quarters for many years. It has been stated by Landon[2] as follows (with modifications added by the writer in italics to include the phase characteristic):

"If in a given low-pass filter, a capacitor is added in series with each inductor, of the proper value to tune it to a frequency f_0; and if an inductor is added in parallel with every (originally present) capacitor of the proper value to tune it to parallel resonance at the frequency f_0; then the bandwidth of the new band-pass filter is exactly the same as the bandwidth of the previous low-pass filter at every attentuation ratio *and at every phase shift*. In the band-pass filter the frequency f_0 is the geometric mean of any two frequencies of equal attentuation *or equal phase shift*."

When the band of frequencies considered is small compared with the mean frequency f_0, f_0 can be taken as the arithmetic mean of any two frequencies of equal attenuation (or phase shift) with but small error.

Class C Amplifier-Tube Equivalent Circuit

Radio-frequency amplifier tubes in transmitters are usually operated class C. As a first approximation, these amplifier tubes may be considered to be current generators independent of the load impedance. As a better approximation they may be considered to be current generators shunted by a high resistance. This resistance is the internal plate resistance of the tube multiplied by a factor which depends on the angle of plate-current flow. This effective internal plate resistance of a class C tube is given by[3]

$$R = r_p \frac{2\pi}{2\theta - \sin 2\theta}$$

where

R = effective internal plate resistance
θ = half the angle of plate-current flow in radians
r_p = internal plate resistance

Response of the Analogous Low-Pass Network

Consider the low-pass network shown in Fig. 1a. The response of this network is

$$\frac{E_2}{E_1} = \frac{1}{j\omega C + \dfrac{1}{r_c}} \; \frac{1}{r_L + j\omega L + \dfrac{1}{j\omega C + \dfrac{1}{r_c}}}$$

$$\frac{E_2}{E_1} = \frac{E_2}{E_1}\bigg]_{\omega=0} \frac{1}{1 - \left(\dfrac{\omega}{\omega_r}\right)^2 + j\dfrac{\omega}{\omega_r} D_r} \tag{1a}$$

$$\frac{E_2}{E_1} = \frac{E_2}{E_1}\bigg]_{\omega=0} \frac{1}{\sqrt{\left[1 - \left(\dfrac{\omega}{\omega_r}\right)^2\right]^2 + \left(\dfrac{\omega}{\omega_r}\right)^2 D_r^2}}$$

$$\angle \tan^{-1} \frac{\dfrac{\omega}{\omega_r} D_r}{\left(\dfrac{\omega}{\omega_r}\right)^2 - 1} \tag{1b}$$

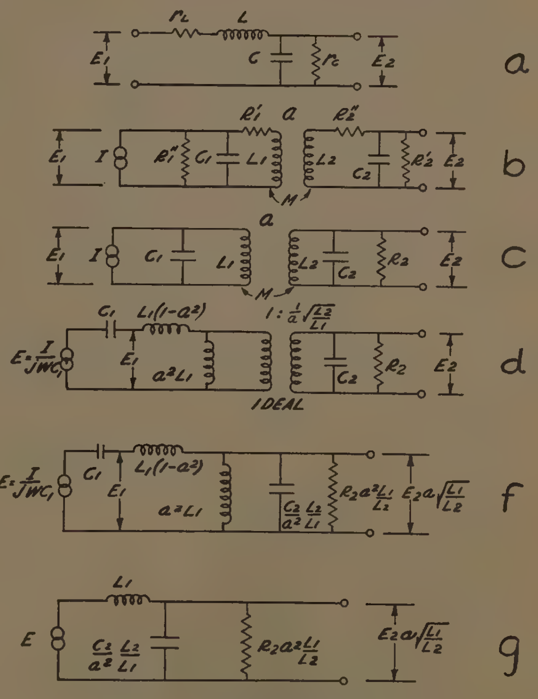

Fig. 1—Equivalent circuits for coupled resonant circuits.

where

$$\omega_r^2 = \frac{1 + r_L/r_c}{LC} \quad \text{the frequency at which phase shift} = 90 \text{ degrees} \tag{1c}$$

$$\frac{E_2}{E_1}\bigg]_{\omega=0} = \frac{r_c}{r_L + r_c} \tag{1d}$$

$$D_r = \frac{r_L}{\omega_r L} + \frac{1}{r_c \omega_r C} \quad \text{the dissipation or damping factor.} \tag{1e}$$

The response of this network is plotted as a function of frequency for various values of D_r in Figs. 2 and 3.

[2] V. D. Landon, "Band-pass—low-pass analogy," Proc. I.R.E., vol. 24, pp. 1582–1584; December, 1936.
[3] W. L. Everitt, "Communication Engineering," Second Edition, McGraw-Hill Book Co., New York, N. Y., 1937, p. 568.

It should be noted that all the curves of Fig. 2 for various values of D_r approach asymptotically an attentuation of 12 decibels per octave removed from ω_r; i.e., at $\omega=2\omega_r$ the attentuation is approximately 12 decibels, at $\omega=4\omega_r$ it is approximately 24 decibels, at $\omega=8\omega_r$ it is approximately 36 decibels, etc.

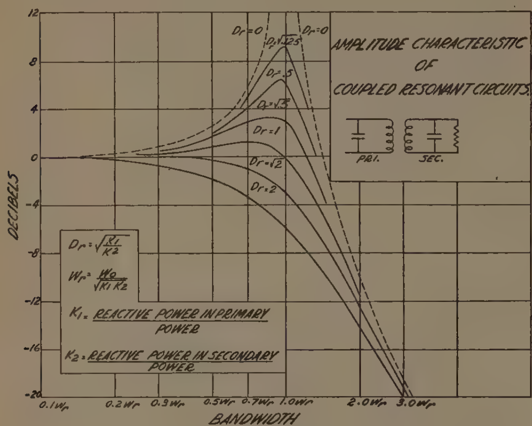

Fig. 2—Coupled resonant circuits for transmitters.

For certain purposes it is desirable to express the amplitude and phase parts of (1b) as infinite power series. These series expansions are

$$\frac{E_2}{E_1}=\left.\frac{E_2}{E_1}\right]_{\omega=0}\left[1-\frac{1}{2}(D_r^2-2)\frac{\omega^2}{\omega_r^2}+\frac{1}{8}\{3(D_r^2-2)^2-4\}\frac{\omega^4}{\omega_r^4}-\frac{1}{16}\{5(D_r^2-2)^3-12(D_r^2-2)\}\frac{\omega^6}{\omega_r^6}+\cdots\right] \quad (1f)$$

$$\theta=-D_r\frac{\omega}{\omega_r}+D_r(D_r^2-3)\frac{1}{3}\frac{\omega^3}{\omega_r^3}-D_r(D_r^4-5D_r^2+5)\frac{1}{5}\frac{\omega^5}{\omega_r^5}+D_r(D_r^6-7D_r^4+14D_r^2-7)\frac{1}{7}\frac{\omega^7}{\omega_r^7}+\cdots. \quad (1g)$$

For the derivation of these expressions see the Appendix.

We are often interested in making the amplitude characteristic "flat." At other times we may be interested in making the phase function "linear." If the coefficient of $(\omega/\omega_r)^2$ in (1f) is made zero, the amplitude characteristic will be "maximally flat."[4]

$$D_r^2=2$$

$$\left.\frac{E_2}{E_1}\right]_{\text{max flat}}=\left.\frac{E_2}{E_1}\right]_{\omega=0}\left[1-\frac{1}{2}\frac{\omega^4}{\omega_r^4}+\frac{3}{8}\frac{\omega^8}{\omega_r^8}-\cdots\right]. \quad (1h)$$

If the coefficient of $(\omega/\omega_r)^3$ in (1g) is made zero, the phase characteristic will be "maximally linear."[4]

$$D_r^2=3$$

$$\theta\Big]_{\text{max linear}}=-\sqrt{3}\frac{\omega}{\omega_r}\left[1-\frac{1}{5}\frac{\omega^4}{\omega_r^4}+\frac{1}{7}\frac{\omega^6}{\omega_r^6}+\cdots\right]. \quad (1i)$$

Element Values in Analogous Coupled Resonant Circuits

A common type of interstage coupling unit used in transmitters is shown in Fig. 1b

where I = current generator equivalent to the driver tube
R_1'' = internal impedance of the driver tube
R_1' = equivalent resistance of the losses in the coil L_1
R_2'' = equivalent resistance of the losses in the coil L_2
R_2' = impedance of the load
$a=M/\sqrt{L_1L_2}$, the coefficient of coupling

In practical transmitters, the effects of R_1'', R_1', and R_2'' are small if not negligible. Hence, Fig. 1b becomes Fig. 1c. The coupled coils may be replaced by an ideal transformer and two inductances[6] as shown in Fig. 1d. By an application[7] of Thevenin's theorem, the current generator I may be replaced by a voltage generator E, in series with the capacitor C_1 as shown in Fig. 1d.

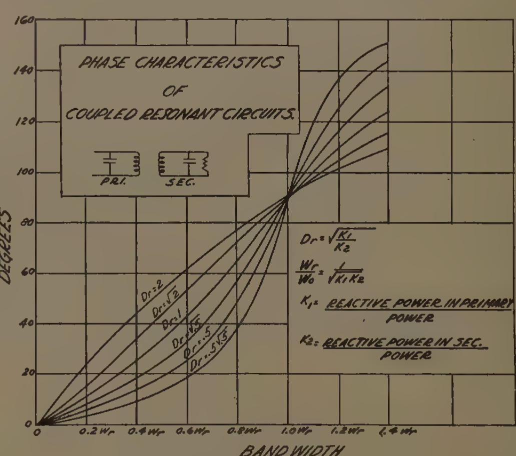

Fig. 3—Phase characteristics of coupled resonant circuits.

The ideal transformer can be removed by an impedance transformation as in Fig. 1f.

If it is assumed that the primary and secondary are tuned to resonance at the same frequency, that is,

[4] Maximally flat is a phrase coined by Landon.[5] A maximally flat curve may be defined as one which approaches a horizontal straight line at a point in such a manner that one or more of the first, second, third, etc., of its derivatives (in order) has been made zero at the point.

A maximally linear curve may be defined as one which approaches a straight line at a point in such a manner that one or more of the second, third, fourth, etc. of its derivatives (in order) has been made zero at the point.

[5] V. D. Landon, "Cascade amplifiers with maximal flatness," Part I, *RCA Rev.*, vol. 5, pp. 347–362, January 1941; Part II, vol. 5, pp. 481–497, April, 1941.

[6] E. A. Guillemin, "Communication Networks," John Wiley and Sons, New York, N. Y., 1935, vol. II, pp. 153–154, Figs. 40 and 42b.

[7] See page 47 of footnote reference 3.

$$C_1L_1(1-a^2) \cong C_1L_1 = \frac{1}{\omega_0^2} = C_2L_2 \qquad (2)$$

where $a^2 \ll 1$

then, the low-pass network analogous to Figs. 1b, 1c, 1d, and 1f is Fig. 1g. The bandwidth[8] at which 90-degree phase shift occurs is, from (1c),

$$\omega_r^2 = \frac{1}{L_1C_2\dfrac{1}{a^2}\dfrac{L_2}{L_1}} = \frac{a^2}{L_2C_2} = \omega_0^2a^2. \qquad (3)$$

The damping factor is, from (1e) and Fig. 1g

$$D_r = \frac{1}{R_2a^2\dfrac{L_1}{L_2}\omega_r\dfrac{C_2}{a^2}\dfrac{L_2}{L_1}} = \frac{1}{a\omega_0R_2C_2}.$$

Defining

$$K_2 = \omega_0R_2C_2 = \frac{R_2}{\omega_0L_2} \qquad (4)$$

as the kilovolt-ampere ratio of the secondary, we obtain

$$D_r = \frac{1}{aK_2}. \qquad (5)$$

In Fig. 1c we can find E_{01}, the value of E_1 at resonance, as follows:

The currents flowing in the secondary at resonance must be

$$I_{R_2} = \frac{E_{02}}{R_2}, \quad I_{C_2} = E_{02}j\omega_0C_2, \quad I_{L_2} = \frac{E_{02}-e_0}{j\omega_0L_2}$$

where e_0 = voltage induced in L_2 due to the current in L_1.

E_{02} = value of E_2 at resonance.

Since the sum of these currents must be zero

$$I_{R_2} + I_{C_2} + I_{L_2} = 0$$

$$\frac{e_0 - E_{02}}{j\omega_0L_2} = E_{02}\left(\frac{1}{R_2} + j\omega_0C_2\right)$$

$$e_0 - E_{02} = E_{02}\left(\frac{j\omega_0L_2}{R_2} - \omega_0^2L_2C_2\right)$$

$$e_0 = E_{02}\left(1 - \omega_0^2L_2C_2 + \frac{j\omega_0L_2}{R_2}\right)$$

$$e_0 = E_{02}\frac{j\omega_0L_2}{R_2} \quad (\text{since } 1-\omega_0^2L_2C_2 = 0).$$

The current in L_1 must be

$$I_{L_1} = \frac{e_0}{j\omega_0M} = E_{02}\frac{L_2}{MR_2}$$

and E_{01} must be

$$E_{01} = j\omega_0L_1I_{L_1} + \frac{E_{02}}{j\omega_0L_2}j\omega_0M$$

$$= E_{02}\left[\frac{j\omega_0L_1L_2}{MR_2} + \frac{M}{L_2}\right]$$

$$= E_{02}\left[\frac{\sqrt{L_1L_2}}{M}\sqrt{\frac{L_1}{L_2}}\frac{j\omega_0L_2}{R_2} + \frac{M}{\sqrt{L_1L_2}}\sqrt{\frac{L_1}{L_2}}\right].$$

From (4)

$$\frac{R_2}{\omega_0L_2} = K_2$$

and from (2)

$$\frac{L_1}{L_2} = \frac{C_2}{C_1}$$

and since $M/\sqrt{L_1L_2} = a$, which is the coefficient of coupling, we find

$$\frac{E_{01}}{E_{02}} = j\frac{1}{aK_2}\sqrt{\frac{C_2}{C_1}} + a\sqrt{\frac{C_2}{C_1}}$$

$$= jD_r\sqrt{\frac{C_2}{C_1}}(1 + ja^2K_2)$$

and

$$\left|\frac{E_{01}}{E_{02}}\right| = D_r\sqrt{\frac{C_2}{C_1}}\sqrt{1+\frac{1}{D_r^4K_2^2}}.$$

Squaring, we obtain the equation

$$\left|\frac{E_{01}}{E_{02}}\right|^2\frac{C_1}{C_2} = D_r^2 + \frac{1}{D_r^2K_2^2}.$$

If we take P as the power through the network, we recognize that

$$\left|\frac{E_{01}}{E_{02}}\right|^2\frac{C_1}{C_2} = \frac{|E_{01}|^2\omega_0C_1}{P}\cdot\frac{P}{|E_{02}|^2\omega_0C_2} = \frac{K_1}{K_2} \qquad (6)$$

where K_1 and K_2 are kilovolt-ampere ratios of primary and secondary, respectively, and therefore,

$$D_r^4 - \frac{K_1}{K_2}D_r^2 + \frac{1}{K_2^2} = 0.$$

Finally, solving the quadratic and taking the correct root

$$D_r^2 = \frac{1}{2}\frac{K_1}{K_2} + \frac{1}{2}\frac{K_1}{K_2}\sqrt{1-\frac{4}{K_1^2}}.$$

If $K_1 > 2$

$$D_r^2 = \frac{K_1}{K_2}\left(1 - \frac{1}{K_1^2} - \frac{1}{K_1^4} - \frac{4}{K_1^6} - \cdots\right).$$

Furthermore, if $K_1 \gg 1$, as is almost always the case,

$$D_r^2 \cong \frac{K_1}{K_2}. \qquad (7)$$

Conclusions

Figs. 2 and 3 give the amplitude and phase characteristics of coupled resonant circuits as a function of bandwidth for various values of the damping factor. The bandwidth is the difference between two frequencies of equal attenuation (or phase shift). The

[8] As stated in the paragraph titled "Band-Pass–Low-Pass Analogy," the term bandwidth means the difference between frequencies of equal attenuation, or phase shift, for band-pass configurations and the actual frequency for low-pass configurations.

product of any two frequencies of equal attenuation is equal to the square of the mid-band frequency ω_0.

The assumptions made are that:

1. The driver tube may be assumed to be an ideal current generator (one whose internal impedance is infinitely high).
2. The dissipation in the coils and capacitors is negligibly small.
3. The degree of coupling between primary and secondary is small enough; i.e., $\alpha^2 \ll 1$.
4. The primary kilovolt-ampere ratio is large enough; i.e., $K_1 \gg 1$.

We can summarize our results as follows:

From (2)

$$C_1L_1 = \frac{1}{\omega_0^2} = C_2L_2. \tag{8}$$

From (3), (5), and (7)

$$\frac{\omega_r}{\omega_0} = \frac{1}{\sqrt{K_1K_2}}. \tag{9}$$

From (7)

$$D_r = \sqrt{\frac{K_1}{K_2}}. \tag{10}$$

From (6) and (7)

$$\frac{C_1}{C_2} = \frac{K_1}{K_2}\left|\frac{E_{02}}{E_{01}}\right|^2 \tag{11}$$

where

$$K_1 = \left|\frac{E_{01}^2\omega_0C_1}{P}\right| \tag{12}$$

and

$$K_2 = \left|\frac{E_{02}^2\omega_0C_2}{P}\right| = R_2\omega_0C_2 \tag{13}$$

are defined as the kilovolt-ampere ratios of primary and secondary, respectively.

The symbols used above are summarized as follows:

C_1 = primary capacitance
C_2 = secondary capacitance
L_1 = primary inductance
L_2 = secondary inductance
ω_0 = mid-band frequency in radians per second
ω_r = bandwidth at which 90-degree phase shift occurs in radians per second
D_r = shape, or damping, factor of the response curves
E_{01} = voltage across the primary at resonance
E_{02} = voltage across the secondary at resonance
P = power transferred through the network
K_1 = kilovolt-ampere ratio of the primary
K_2 = kilovolt-ampere ratio of the secondary

Acknowledgment

The writer is grateful for the inspiration of Mr. V. D. Landon, to whom he is indebted for many of the concepts and methods of attack used in this paper.

Appendix I

Power Series Expansions of Amplitude and Phase Characteristics of the Low-Pass Analogy to Resonant Coupled Circuits

$$[(1-\delta^2)^2+\delta^2D_r^2]^{-1/2} = [1+\delta^2(D_r^2-2)+\delta^4]^{-1/2}$$

$$\begin{aligned}
[1+\delta^2(\alpha^2+\delta^2)]^{-1/2} &= 1-\frac{1}{2}\delta^2(\alpha^2+\delta^2)+\frac{3}{8}\delta^4(\alpha^2+\delta^2)^2-\frac{5}{16}\delta^6(\alpha^2+\delta^2)^3+\cdots\\
&= 1-\frac{1}{2}\alpha^2\delta^2-\frac{1}{2}\delta^4+\frac{3}{8}\alpha^4\delta^4+\frac{3}{4}\alpha^2\delta^6+\cdots-\frac{5}{16}\alpha^6\delta^6+\cdots\\
&= 1-\frac{1}{2}\alpha^2\delta^2+\frac{1}{8}(3\alpha^4-4)\delta^4-\frac{1}{16}(5\alpha^6-12\alpha^2)\delta^6+\cdots\\
&= 1-\frac{1}{2}(D_r^2-2)\delta^2+\frac{1}{8}[3(D_r^2-2)^2-4]\delta^4-\frac{1}{16}[5(D_r^2-2)^3-12(D_r^2-2)]\delta^6-\cdots
\end{aligned}$$

$$\theta = \tan^{-1}\frac{\delta D_r}{\delta^2-1} = -\tan^{-1}\frac{(a+b)\delta}{1-ab\delta^2} = -\tan^{-1}a\delta-\tan^{-1}b\delta$$

where

$$ab = 1$$
$$a+b = D_r$$

$$\theta = \left[-a\delta+\frac{1}{3}a^3\delta^3-\frac{1}{5}a^5\delta^5+\cdots\right]+\left[-b\delta+\frac{1}{3}b^3\delta^3-\frac{1}{5}b^5\delta^5+\cdots\right]$$

$$\theta = -\left[(a+b)\delta-\frac{1}{3}(a^3+b^3)\delta^3+\frac{1}{5}(a^5+b^5)\delta^5-\cdots\right]$$

$$\begin{aligned}
\theta = &-(a+b)\delta+[(a+b)^3-3ab(a+b)]\frac{\delta^3}{3}-[(a+b)^5-5ab(a+b)^3+5ab(a+b)]\frac{\delta^5}{5}\\
&+[(a+b)^7-7ab(a+b)^5+14ab(a+b)^3-7a^2b^2(a+b)]\frac{\delta^7}{7}-\cdots
\end{aligned}$$

$$\theta = -D_r\delta+D_r(D_r^2-3)\frac{\delta^3}{3}-D_r(D_r^4-5D_r^2+5)\frac{\delta^5}{5}+D_r(D_r^6-7D_r^4+14D_r^2-7)\frac{\delta^7}{7}-\cdots.$$

Postwar-Radio Planning*

JAMES LAWRENCE FLY†, NONMEMBER, I.R.E.

THIS IS an opportunity to which I have looked forward. It's always a bit awe inspiring to undertake to get the experts told. It does permit me to congratulate the Institute of Radio Engineers upon its selection of Doctor L. P. Wheeler for its president during 1943. It has been my good fortune to have had the benefit of Dr. Wheeler's counsel and assistance ever since I have been with the Commission. As Chief of the Technical Information Division of our Engineering Department, Dr. Wheeler has brought to the Federal Communications Commission all of his experience as a teacher at Yale and as a research physicist at the Navy's laboratories at Bellevue. The background of electronics at his command has served us well in coping with radio problems. The Commission appreciates having a member of its staff so recognized by this outstanding group of radio engineers.

It has been remarked that the war in which we are engaged is the greatest technical and engineering war of all time. It is being fought by machines—flying through the air, rolling over the ground, sweeping over the oceans, or gliding underneath the surface of the seas. All these are machines which must be supplied with most complex and delicate instruments. History may record radio supremacy as comparable in importance to the control of the seas. There are none more fully aware of the part that radio is playing in this war than you who are here this evening. An irritating squawk and fascinating toy twenty-five years ago, today it quickly co-ordinates our military and naval operations; locally in the case of individual ships, airplanes, and tanks; and across the seas in the case of whole armies and task forces. The date lines on daily news stories show how far afield our various machines of war operate. None operate more remotely than our submarines. Incidentally, it may surprise many of you to learn that the man who will be the IRE president in 1943 contributed a great deal to make these submarine operations possible. Over long periods he conducted research inside a "pig boat" as it lay on the bottom of Hawaiian waters. His work on electronics has done much to make our submarines the most feared in the world.

Radio, along with other communications, is playing another role. It helps to tie more closely the fighting forces with those at home. Modern conscription of the masses for war service, beginning with Napoleon, has called for a greater and greater part to be played by the citizen with each succeeding war. War today is no longer impersonal even to noncombatants. The war today is called a "People's War" largely because of the ideology that surrounds the conflict. I think too that radio has helped to make it a "People's War." Bridged by radio, the soldier on the battlefront and the citizen on the home front are nearly one in thought and attitude during the trials and fortunes of battle.

Our industrial radio machine and our national communications system have been making adjustments for conversion from peace to war work. The progress we have made so far in converting radio to its war role was ably discussed by the Presidents of the Institute of Radio Engineers and the Radio Manufacturers Association at the IRE convention in Cleveland last June. We now have our manufacturing plants and our communications systems going with ever-increasing momentum and we plan to keep it so until we have won.

It has been as gratifying to you, I am sure, as it has been to me to receive reports from time to time from our fighting men that indicate that their radio equipment is matching our highest hopes. However, we must not relapse into overconfidence. We will have to await the outcome of the final battle before relaxing for a moment. The demands upon radio are heavy, and there are still many problems to be licked. This Association can help. From this meeting with fellow workers in allied lines, seeing them, talking with them, exchanging ideas,—we can go back to our jobs with new perspective and new inspiration. Often from our discussion of some troublesome problem, there emerges a solution that has been just around the corner.

I want to look around the corner briefly and to discuss postwar radio with you. Radio moves so fast that we have to keep peering into the future. In doing so, we are unable to see sharply and clearly, with strong contrasts and good definition. But we can see rough shapes and enough outlines to guess at what's coming.

We know that after this war our radio machine will be plunging ahead with a far greater speed. The machine cannot be stopped nor even permitted to slow down. At that time we will have to readjust its direction and continue to move ahead. The energy required to make this change will be great. I want, therefore, to suggest that you consider the formation of a committee or committees to work on postwar problems. Such committees might well be organized on the model of the National Television Standards Committee, which, under the effective leadership of W. R. G. Baker and James Knowlson rendered great assistance in the preparation of standards for television.

In passing, I should be derelict should I let another occasion pass without recognizing the work of Ewell

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† Chairman, Federal Communications Commission, Washington, D. C.

K. Jett. He is a man of effective personality and an untiring devotion to duty and he has been of great assistance in the Commission's problems of administration. He is the spark plug of the Board of War Communications. Search though you may through Government, the Army, and the Navy, and the industry, you cannot find another man of such broad competence in the field of world communications. Mr. Jett will stand ready to work with your industry organization.

I know of no organization better qualified to initiate this suggested work than those that are represented here tonight. In the Radio Manufacturers Association and the Institute of Radio Engineers, there exist two great organizations in which are co-ordinated practically all activities of the radio industry. There are pure scientists, mathematicians and teachers, laboratory workers, experimenters and inventors, designers and developers, organizers and standardizers, managers, manufacturers, administrators, and all the rest. To this project, however, we must add regulators too, for it surely is advisable to include representatives of the Commission in the discussion of these important problems. In fact, the list of committee members should be representatives of all parts of the field, for radio has become a very broad term indeed. We no longer think of it as associated solely with communications such as broadcasting, radiotelegraphy, and the like. It is rapidly infiltering into almost every phase of our lives. In the postwar period it unquestionably will be as important and vital a factor in industrial conversion and economic reconstruction as it is now on the battlefronts.

As I said before, we shall not be able to see in the future any pictures of sharp outline, but the nearer we approach, the clearer shall we see the things that are there. A committee already set up and functioning will be able to make use of its experience and make provisions in plans and policies in the light of newer conditions. It will be better able to appraise and aid in the exploitation of discoveries which wartime research will surely bring forth. We know that work must be started and plans prepared if we are to win the peace that follows without undue hardship and distress. In addition to the problems of readjustment, reorganization, reconversion of plant equipment, and the many others with which we have had experience in passing from peace to war, there are others which we can see most clearly at this time.

First: We can confidently predict a great expansion of the television and frequency-modulation broadcast and general communications services, and planning for their proper development is definitely in order. As you know, the present plant and status of the broadcasting industry is practically frozen, both by license and priority regulations. Therefore a committee working on this problem can do so with relative confidence because depreciation and obsolesence of existing plants are running on just as usual. With time, and the possibility of fully developed plans for television and frequency modulation and improvements in the other fields, the economic obstacles normally facing new technological advances will be of less concern. This will be particularly true where our business executives see that sound depreciation policies continue to be employed.

Second: Somewhat related to the first problem is the fact that there will be a great surplus of radio war equipment. In addition, there will be new types which are the result of new developments and inventions which may not be revealed at this time. The disposal of this equipment certainly constitutes a major objective.

Third: There will be many thousands of men with new skills gained in the armed forces—skills in radio which will have to find a place. Then there are the many women who have absorbed skills in radio repair and installation while working in the aircraft factories and other plants now devoted to war production. It is certain that an appreciable proportion will want to continue in this line of work. Employment for all of these people, who most certainly will want to work with us in radio, is something to think about at this time.

Fourth: Radio has been on the move into fields other than communications. This trend started even before the war. In the case of medicine and surgery as many as 80,000 diathermy machines have been registered with the Commission; and this hardly indicates the extent to which radio is being used for the relief of human ills. Radio is moving rapidly into industrial applications too, for precision measurements and testing and for the synthesis, manufacture, and processing of new materials. Its progress needs to be carefully watched in this direction as it is likely to become an essential and invaluable tool of almost every modern industry. Better health, comfort, convenience, and safety are only a few of the boons which postwar radio will give mankind.

In this connection I would like to quote from a recent institutional ad of the New York *Times*, which expresses the thought very well. In this ad there is a striding American soldier with a walkie-talkie on his back. The reader is startled by the statement that the tube upon his back will save a million lives. To go on, it states:

"Under the flaring northern lights at the fringe of the great ice, on craggy Pacific islands, in the desert sands of Africa, Americans are holding a world-wide front. Against Odds!

"But they have a new protection. A voice that can penetrate the noise of a tank, that can search out a shadowy group lost in a jungle, that can direct a plane in flight. A voice that can warn of lurking killers or threatening flankers. A voice that can comfort or command as needed.

"That voice comes from a pack upon the speaker's back. In that pack there is a tube. That tube is the secret of an immense new power that we are learning to control.

"It is the electronic tube.

"Today it will save thousands of lives that must otherwise have been sacrificed to war. Tomorrow it will save millions by preventing accidents, by improving medical and surgical practice. Electronics can see into germ structure or through the utter blackness of night and fog with equal ease. It can smell out poisons, anticipate fires, guarantee food values, assure the perfection of manufactured goods.

"In many ways it is a symbol of this war.

"For actually we are fighting to determine whether the fruits of science shall be used for our enslavement or our enjoyment.

"If we lose, this latest great achievement of man will supply the victor with the jailer's unfailing eye, the pitiless supervisor of slave labor, the impassable wall of the concentration camp.

"But if we win, electronics will provide new work and happiness for millions of Americans.

"Throughout the world it will make possible a better life."

So, gentlemen, your public awaits you. The people already have an idea of what is in your power.

It is quite probable that in the postwar period we shall become the world's principal suppliers of radio equipment. We shall have to make provision for this export trade. And in this connection we must not overlook the potential importance of international broadcasting as a method of assuring an enduring peace. New methods and techniques may be found in the broadcasting of sound and pictures to peoples of foreign lands to give visual and living emphasis to aspirations common to people of good will everywhere. Color television must be developed. The distance limitations hitherto imposed upon television must be broken down. You engineers already have a pincers movement underway against this one obstacle. We are bound to have a feasible method for the long-distince relay of television by high-frequency emissions.

We can never forget the allocation and interference problems. They are always with us. We may expect the present congestion in the lower regions of the spectrum to increase rather than diminish. We are going up. In the upper regions of the spectrum we must prepare for expansion. Fortunately, it is virtually certain that we will be ready to make some immediate use of that portion between the present upper top of approximately 150 megacycles to at least 3000 megacycles. While we advance into wider spaces the uses of radio multiply, and the problem of allocation continues to haunt us. This may appear at first sight to be purely the Commission's pigeon, but that is not so. For allocation engineering is also one of these specialties peculiar to radio which is not so simple as to permit the Commission to proceed alone. You are always concerned, and assistance from you experts of the industry has always been freely given. We shall continue to rely upon that assistance.

Radio has been called a science and it has been called an art. It is something of both. When I think of radio, I always think of the grand engineers who have developed this important science through the decades. But we cannot ignore the sound and telephone experts or the optical and photographic specialists, on the one hand, nor can we forget all the artists, announcers, production managers, and program people, on the other. The postwar problems are so interconnected that, should you act upon my suggestion the committees which go to work upon them will require the collaboration and assistance of a number of organizations. But this should not be difficult. That assistance will not have to be sought—it will be volunteered. Everyone in radio is seeking to contribute his share. And why not? There is a great vista ahead which we shall fully exploit at the end of the war.

Engineers and scientists commonly say: "What is your problem? We can't do anything if we don't know what we have to look for." I hope that I, as a layman, have been of some little assistance in reminding you of some of our "problems" and that you will start "looking for" the answers.

I.R.E. and the War*

ARTHUR VAN DYCK†, FELLOW, I.R.E.

WE ARE nearing the end of our first year of war. It has been a year of preparation, necessarily. The national effort, not having been geared for war, has had to be redirected toward new aims and to use new methods and tools. Similarly with the Institute of Radio Engineers; it has had to be a year of preparation, of clearing for action, of getting ready for the decisive efforts ahead.

The Officers and the Board of Directors have given much time during the year to this preparation and planning. You will see the evidence shortly in proposals to the membership of measures designed to enable the Institute better to meet the new conditions, and better to assist toward winning the war and winning the peace.

Among those proposals is one for revision of the membership-grade structure of the Institute, in such manner as to provide an additional grade between the present Member and Associate grades, of intermediate requirements, and limited to those actually in radio and allied fields.

The new grade will meet a long-felt need for a professional classification less stringent than the present Member grade. It will be especially appropriate in the enormous war expansion in the number of people engaged in various technical branches of radio, with varying degrees of professional competence.

Insofar as immediate efforts are concerned, I think the job can be outlined in a five-point program.

One task is to aid in the allocation of radio man power to maximum service in the war effort. A little has been done on this in connection with the National Roster, but much more remains to be done. The conflicting requirements of Selective Service and various other radio personnel demands need to be compromised, with the exercise of maximum information, wisdom, and judgment. Steps to accomplish this end are under way. Personnel-readjustment conditions after the war will be serious, and perhaps we can make preparations soon, which will lessen the later problem.

Another task is to aid in the standardization and simplification of radio parts and equipment used by the armed forces. This is one of drudgery, a maximum of work, and a minimum of reward, but is one which is the obligation of engineering societies to conduct as a part of their professional, impartial, technically sound contribution to industry and the nation. Its benefits are incalculable. They are not only contributions to more efficient production of apparatus, but have highly desirable effects upon the operation of apparatus in the field.

Next it is necessary to broaden the scope of operations of the Institute, in order to accord with the increasing sphere of radio's influence. Once upon a time radio was merely a point-to-point telegraph communication means, then telephony was added, then mass communication, or sound broadcasting. And then came vision by radio. Now we have in view still more applications of radio-frequency wonders, which I can conveniently and fortunately avoid having to name by adopting the necessary and very popular cloak of military secrecy.

The whole field of electronics is in process of broadening, although not quite so prismatically as advertising copy writers occasionally describe the picture, but *we* are concerned only with those fields which involve radio frequency. Recently, I heard a new term for these new radio fields which seems apt. It is "radionics." That seems to be a good term, if we want to find one which will win friends and influence people. However, in this matter of terminology, I hope that engineers will remain sound and sensible, and I want to utter a word of warning.

In the past we have seen commercial and advertising interests place more importance on names and slogans than on technical soundness, and come to grief after a flurry of excitement which looked like success for a while. Now that engineers are just entering into the period of more influence in planning and administration, I hope that they will not make the mistake of forsaking the path of technical rectitude for the glitter of side-show-barker methods. It doesn't work in the long run anyway, because you can't change Nature's laws by giving them fancy names, and it backfires on the industry which tries it. In the past few years there have been some attempts in the radio industry to substitute promissory words for real service delivered. Let us not have any more of this but instead, as we broaden our field of activity, let us as ethical, professional men, stick to facts, and practical, useful facts, too, in all our dealings with the profession, the industry, the government, and the public.

A necessary item in our program is to maximize the efficiency of our own organization. Progress has been made toward this, but more remains to be achieved. It will interest many of you who have previously recommended the step, to learn that a Section has been instituted in New York. This will not only free the National office of local matters, but will undoubtedly increase the extent and interest of activities in the New York area. Other plans for improving operations are under consideration.

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A fifth step, advisable to take soon, is that of postwar planning for radio and radionics, particularly television. There was a time when the Institute was very active in co-operation with commercial and governmental agencies in new radio matters. But, about 1930, there came such a large and sudden expansion in radio technique, that Institute activities unconsciously became concentrated on the purely technical aspects of the new developments. Thus it came about that even such important developments as international broadcasting, television, and ultra-high-frequency broadcasting, received little attention from the Institute except as subjects of technical interest, involving papers to be published for the information of the membership. The situation was not realized at the time, but we can see now that the Institute missed an opportunity to render those services which may properly be expected from the professional engineering society of the industry. Now that it is realized, we should perform accordingly in the future, and it should be possible for the Institute to aid materially in postwar industrial activities. Such aid will include furnishing authoritative information and recommendations in many industry matters, and assistance in the adjustment of dislocations in technical personnel. Of course, there will be a tremendous job of publication to do, in papers which will have been withheld throughout the war. In general, radio has now grown up, and its engineering association should take the place therein, which other engineering associations have taken in their older industries.

If substantial efforts are to be applied immediately at the end of the war, when they will be needed most, planning should be undertaken now. There are some things which ought to be done in the near future, if they can be done without loss to the war effort, which of course must come first. And I would like to suggest that, while it is necessary to think about the conversion of war discoveries to peacetime utilizations, we should be realistic enough to appreciate that radically new things can have only small benefit in the early postwar period. Time is required for introduction and growth of new things to a magnitude which means much to basic matters such as employment of large numbers of workers. In other words, there will be a "switchback" period, which, if it is to see large-scale activity must depend upon things not wholly new, and which have some war or prewar experience and facilities already available. If we take care of the "switchback" period, the later period will be much easier to take care of, and probably will take care of itself.

Radio is probably unique among American industries in that it has available such a new service and one of vast possibilities. That one is television, which passed through its incubation period before the war, and can be made ready quickly for full service, with only minor time and effort to incorporate the moderate degree of improvement which war developments will have made possible.

So I think that our five-point program should include postwar planning, and that the radio industry is a fortunate one in that it has not only a later postwar period of enormous promise, but can have as well an early postwar possibility of quick usefulness.

In the meantime, radio engineers are devoting time and overtime in helping to win the war. They will be entitled to good vacations when it is over, but even then they are not likely to get them. The Armistice of this war, in distinction to World War I, will be heralded by radio loudspeakers all over the world. Those welcome sounds will mark not only the end of the conflict, but the beginning of a new period in which radio engineers will have many new problems in the vital duty to translate radio possibilities to peacetime benefit as rapidly as possible.

At various times during the past year, in talking about the future, I have emphasized the need for broader vision on the part of scientists and engineers, a larger participation by them in affairs of the everyday world, and a larger voice in the utilization of their output. It is not necessary or desirable to dwell upon that idea again in this statement. But it is perhaps appropriate to conclude with these words of L. A. Hawkins[1] of the General Electric research laboratory which should inspire any engineer who has appreciation of the high responsibility of his profession.

"We have seen the far greater number and complexity of the problems now confronting us. We have seen the number of scientists engaged in war research increased from hundreds to thousands, and their expenditures from millions to tens of millions of dollars. Are we now to look forward to the organization, in another twenty-five years, of tens of thousands of scientists, spending hundreds of millions of dollars, to attack the still more numerous problems of still more mechanized and still more terrible war? Or this time shall we finish the job?

"When victory is won, and the consequent emotional let-down brings war-weariness sweeping over us in waves, shall we again permit our isolationists to lead us back into the primrose paths of so-called 'normalcy,' leaving the world in an international chaos to breed still more sanguinary conflicts? Shall we again pour out our blood and treasure to 'make the world safe for democracy,' and then desert the task just when we have won the power to complete it? Or shall we finish the job, joining with the other free nations in intensive, sustained, and unselfish cooperation, to erect upon the field of victory, around the corner-stone of the Atlantic Charter, a new world structure, to which all nations of good will may resort to find liberty, security, and opportunity, and which will be so strong that no gangster nation will dare attack it?

[1] L. A. Hawkins, Gen. Elec. Rev., June, 1942.

"Are we to go down in history as the generation which twice had offered to it the greatest opportunity in the history of mankind, and twice refused it in selfish stupidity, or are we to be recorded as the generation which fought and won the world's last and greatest war, and established the world's first enduring peace?"

The answers to those questions will be largely determined during the next ten years. We men of science, accustomed to planning on a basis of facts and control of Nature's laws, have an opportunity to assist others toward a realization that there is a scientific way to design all affairs of men, not merely their buildings, bridges and radios. The scientific way is constructive, not destructive, and leads to more joy and even more profit. Let us show the way.

Correction

"Theory of Antennas of Arbitrary Size and Shape"

S. A. Schelkunoff

Correction

S. A. Schelkunoff, whose paper, "Theory of Antennas of Arbitrary Size and Shape," which appeared on pages 493 to 521 in the September, 1941, issue of the Proceedings, has brought to the attention of the editors an error in Fig. 9 of his paper. This is an isolated error and does not affect either the reactance formula or other formulas and curves depending on it. The corrected figure is shown to the right.

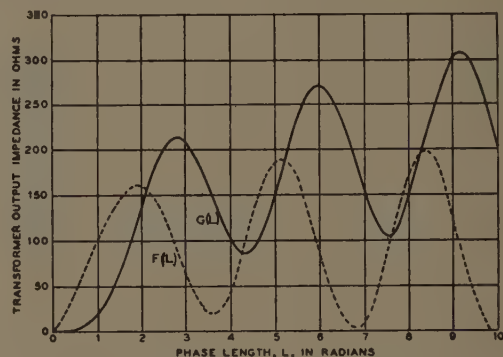


Fig. 9—The real and the imaginary parts of the "transformed" output impedance $K^2/Z_t=G(L)+iF(L)$, where $L=2\pi l/\lambda$.

Institute News and Radio Notes

Winter Conferences—1943
January 28, 1943

As this notice is being written, in early December, 1942, it appears that Boston, Buffalo-Niagara, Cincinnati, Montreal, Portland, St. Louis, San Francisco, Toronto, Washington, and other Institute Sections will hold meetings on or near Winter Conference Day, designated by the Board of Directors to coincide with the date of the Annual Meeting in New York, January 28, 1943. Connecticut Valley, New York, and Philadelphia Sections will throw their support to the all-day Annual Meeting, which, as announced in the December PROCEEDINGS, will be held jointly on that date with the National Technical Meeting of the American Institute of Electrical Engineers in the Engineering Societies Building, 33 West 39 Street, New York, N. Y.

Each Section will circularize its membership as to time, place, date, and all particulars of its meeting, wherever one is being held. The Cincinnati, New York, San Francisco, and Washington Sections have already contributed papers and made them available for other Sections' use; Montreal, Philadelphia, Pittsburgh, and Toronto Sections are among those active in obtaining other papers for similar disposition.

Nationwide Hookup

Through the initiative of the Washington Section, Captain E. M. Webster, United States Coast Guard, chairman; a coast-to-coast radio hookup has been obtained over the facilities of the Columbia Broadcasting System, from 10:30 to 10:45 P. M., Eastern War Time, January 28, for the broadcasting of ceremonies linking the Washington banquet and the New York meeting. Sections which can make suitable dispositions of their meeting schedules will tie in with this feature through locally arranged public-address systems. The event will be of widespread interest to Institute members in their homes throughout the United States and Canada. The newly inducted President of the Institute for 1943, Dr. L. P. Wheeler, will broadcast a brief word of greeting from New York, following an introduction by the Junior Past President, Arthur F. Van Dyck.

Washington

The radio program will then be shifted to Washington, where that Section, holding a banquet at the Willard Hotel, will be in front of the microphone while the Honorable James Lawrence Fly, chairman of the Board of War Communications speaks during the remainder of the 15-minute broadcasting period.

This radio event is but the finale of a full evening's program planned by the Washington Section, carrying out the theme "Radio Goes to War!" A technical papers' session of an hour or more at the Willard, under the chairmanship of Fred W. Albertson, will get under way at 5:00 P. M., followed by a social get-together preceding the banquet at 8 o'clock. Gerald C. Gross heads the banquet committee, and he has scheduled a grand evening of entertainment. Captain Webster, who is in general charge of the evening's events, will pass the Section gavel to the new chairman, Clyde M. Hunt, during the ceremonies.

All members of the Institute temporarily or permanently in Washington, their wives, and their friends are cordially invited to attend. Tickets are obtainable from Mr. Gross whose telephone number is Executive 3620.

New York

The day's activities at New York, on January 28, will open with a technical session, beginning at 10:00 A. M. A folder giving the names of papers and authors and describing the entire day's events will be mailed to the Connecticut Valley, New York, and Philadelphia membership a reasonable time prior to the Annual Meeting.

The following papers will be presented Thursday morning, January 28 from 10:00 A. M. to 12:30 P. M.

- "Radio-Frequency-Operated High-Voltage Supplies for Cathode-Ray Tubes," by O. H. Schade, RCA Manufacturing Company, Harrison, N. J.
- "Transmission-Line Charts," by R. S. Julian, Bell Telephone Laboratories, Whippany, N. J.
- "Polydirectional Microphones," by H. F. Olson, RCA Manufacturing Company, Camden, N. J.
- "Phosphors and the Periodic System of the Elements," by H. W. Leverenz, R.C.A. Communications Laboratories, Princeton, N. J.

Annual Meeting

In accordance with provisions of the Constitution, the Annual Meeting of the Institute will be held in the Engineering Societies Building, 33 West 39 Street, New York, N. Y., at 2:30 P. M., January 28, 1943. This

announcement constitutes legal notice thereof.

The annual report of the Secretary will be received.

Past-President Van Dyck will give an account of his term of office and the trend of Institute accomplishment. He and President Wheeler will then engage in the traditional ceremony of transferring the gavel as the symbol of office, with appropriate remarks by Dr. Wheeler.

The Institute Medal of Honor will be presented to William Wilson for his achievements in the development of modern electronics, including its application to radiotelephony, and for his contributions to the welfare and work of the Institute.

Fellowships of the Institute will be conferred on the following:

Andrew Alford for his contributions to the theory of radiation and the design of short-wave antennas.

Ivan S. Coggeshall for his services to the welfare of the Institute and the engineering profession.

Captain Jennings B. Dow for engineering accomplishments in the development and procurement of radio equipment for the United States Navy.

Lee A. DuBridge for engineering and administrative leadership in the development and application of new radio techniques.

Peter C. Goldmark for his contributions to the development of practical color television.

Daniel E. Harnett in recognition of his outstanding direction of radio engineering activities.

Dorman D. Israel in recognition of his contributions to the engineering of broadcast receivers.

Axel G. Jensen for his constructive participation in the development of the short-wave transatlantic telephone, the development of broad-band, multichannel telephony, and the art of television.

Lieutenant Colonel George F. Metcalf for his development work on vacuum tubes and vacuum-tube circuits and the successful co-ordination of many technical projects requiring broad scientific knowledge.

Irving Wolff for basic research in centimeter-wave radio and application of it to the development of navigation instruments.

The special-papers symposium, with which the Annual Meeting will be concluded, takes its color from current world events, to which the radio engineer is contributing more than a full share of influence. In a technological war, distinguished members of the Institute are to be found engaged in tasks quite foreign in purpose to those which occupied them in times of peace, some of them in their accustomed locale while others are in the armed forces and in Government agencies prosecuting the war. The work of many of them imposes strict secrecy. With respect to others, certain phases of their work may be explained for the benefit and education of other members of the Institute. Several of these men have consented to address the Institute at its Annual Meeting. Lloyd Espenschied will set the stage with a brief summary paper on radio in two World Wars. Rear-Admiral S. C. Hooper of the United States Navy will speak on "The Production of Radio Facilities for the Armed Services," Ray Ellis, Director of the Radio-Radar Division of the War Production Board will address the group on "The Function of the War Production Board in Radio." "The Army-Navy Electronics Production Agency," will be discussed by F. R. Lack, Director of that agency. H. P. Westman of the War Committee on Radio, American Standards Association, will speak on "Radio Standards Go to War." Kirk Miles of the National Roster, War Manpower Commission, will describe the engineer's function in selective service and manpower plans.

Evening Meeting

The day's events will culminate in a joint A.I.E.E.–I.R.E. technical meeting at 8:30 P. M., on the subject of Ultra-High-Frequencies, the address being given by Dr. George C. Southworth of Bell Telephone Laboratories, Inc. Doctor Southworth, a Fellow of the I.R.E., has previously given two notable addresses on this general subject before the I.R.E. and various Sections of the A.I.E.E. The Institute values greatly this privilege of joining with its sister society in hearing Doctor Southworth.

A.I.E.E. Joint Activities

Members of the Institute of Radio Engineers have been extended a cordial invitation by the American Institute of Electrical Engineers to attend any of the sessions of A.I.E.E. held during the period of their five-day meeting, January 25 to 29. Maximum aid to the war effort will be the principal theme for most of their sessions and conferences. Arrangements are being made for a program on the subject of technical manpower requirements to aid the war effort, with prominent speakers presenting both the military and industrial phases of the subject. Many of the sessions will deal with utlizing existing electrical equipment to the utmost in order to conserve copper and other critical materials.

Of especial interest to I.R.E. registrants are:

- A symposium on Varistors and Thermistors, to be held under the auspices of the A.I.E.E. Communication Committee.
- A conference on Industrial Electronics.
- Award of the Edison, John Fritz, and Hoover Medals, on Wednesday evening, January 27.

The I.R.E.–A.I.E.E. co-operating committees consists of Messrs. F. A. Cowan and Louis Pacent, for the A.I.E.E., and Messrs. H. A. Wheeler, D. D. Israel, and I. S. Coggeshall, for the I.R.E. In addition, the Institute Committee consists of Mr. H. M. Lewis, chairman of the New York Section, acting as chairman of a subcommittee on registration, and Dr. Austin Bailey, chairman of the subcommittee on program.

Registration

There will be an I.R.E. registration desk open in the lobby for the issuance of badges to I.R.E. members and their guests at the morning and afternoon sessions of Thursday, January 28, only. I.R.E. members only, desiring to attend A.I.E.E. sessions on any day except Thursday, should register as a guest of the A.I.E.E. at their lobby registration desk, by courtesy of that society.

Board of Directors

A regular meeting of the Board of Directors was held on December 2, 1942, and was attended by Haraden Pratt, acting chairman; Austin Bailey, C. C. Chambers, I. S. Coggeshall, W. L. Everitt, H. T. Friis, O. B. Hanson, C. M. Jansky, Jr., F. B. Llewellyn, B. J. Thompson, H. M. Turner, H. A. Wheeler, L. P. Wheeler, H. P. Westman, secretary; and W. B. Cowilich, assistant secretary.

The resignation of Secretary Westman to be effective December 15, 1942, was accepted.

In view of modifications which are being made in the editorial procedure and staff, Helen M. Stote was advanced from assistant editor to associate editor.

The 1942 Budget was revised to show receipts and disbursements of approximately \$104,000 and \$92,000, respectively.

President-elect Wheeler is serving on the Board of Directors as an elected Director whose term expires at the end of 1943. In order to avoid a vacancy on the Board of Directors, his resignation as an elected Director for 1943 was accepted.

The service of President Van Dyck as a representative of the Institute on the Consultative Committee on Engineering of the Division of War Manpower Commission of the Office for Emergency Management and of Mr. Pratt as an alternate, was approved.

Mr. Thompson was appointed to investigate the problem of the status of radio engineers under Selective Service. The Executive Committee was empowered to appoint a committee on this subject.

On recommendation of the Awards Committee, the Medal of Honor for 1943 was voted to William Wilson for his achievements in the development of modern electronics, including its application to radiotelephony, and for his contributions to the welfare and work of the Institute.

The following addition to the Constitution for Sections, adopted by the Sections Committee as a result of its annual meeting on June 29, 1942, was approved.

ARTICLE VI

Sec. 6—The Chairman shall, when notified of the Annual Meeting of the Committee on Sections, arrange for representation of his Section at such Annual Meeting by himself or by some member of his Section or he shall forward a letter to the Committee Chairman explaining inability to provide representation and giving the views of his Section on the agenda or proposals before the meeting.

Failure to comply with the above shall be punished by a fine of \$10.00 to be deducted from the rebates to the Section. Sections so remotely located as to make the requirements unusually difficult, may be excused by the Sections Committee from these penalties.

The above penalty shall not be exacted if the Chairman of the Sections Committee shall fail to forward to each Section Chairman and Secretary, at least forty-five days in advance of the date of the Annual Meeting of the Sections Committee, notice of that meeting and the agenda to be considered thereat.

Executive Committee

A meeting of the Executive Committee which was attended by A. F. Van Dyck, chairman; I. S. Coggeshall, Alfred N. Goldsmith, R. A. Heising (guest); F. B. Llewellyn, Haraden Pratt, B. J. Thompson, and H. P. Westman, secretary; was held on November 12, 1942.

The meeting was devoted to a discussion of the office organization, the operation of the Institute, and the appointments to Institute Committees.

On November 20, 1942, the Executive Committee met. Those present were. A. F. Van Dyck, chairman; I. S. Coggeshall, Alfred N. Goldsmith, R. A. Heising (guest) F. B. Llewellyn, Haraden Pratt, B. J. Thompson, L. P. Wheeler, (president-elect); and W. B. Cowilich, assistant secretary.

Several matters pertaining to the operation of the office and of the personnel were considered.

The financial operations of the Institute for the first ten months of 1942 were discussed.

The Executive Committee met on December 2, 1942 and those present were Haraden Pratt, acting chairman; I. S. Coggeshall, R. A. Heising (guest); F. B. Llewellyn, B. J. Thompson, L. P. Wheeler, (president-elect); H. P. Westman, secretary; and W. B. Cowilich, assistant secretary.

Certain revisions in the budget for 1942 were discussed and were recommended to the Board of Directors for adoption.

A proposed amendment to the Constitution for Sections was considered and recommended favorably to the Board of Directors.

Applications for transfer to Member in the names of A. B. Bailey, H. V. Griffiths and J. A. Stobbe, and for admission to Member in the names of J. C. Bayles, S. T. Fisher, and D. L. Hathaway, were approved.

Approval was granted to 82 applications for Associate, 179 for Student, and 6 for Junior.

Books

Mathematics for Electricians and Radiomen, by Nelson M. Cooke

Published by the McGraw-Hill Book Company, 330 West 42 Street, New York, N. Y. 595 pages+7-page index+viii pages. 301 figures. $6\frac{1}{2}\times 9\frac{1}{4}$ inches. Price, \$4.00.

As indicated by the title, this book was written for electricians and radiomen having little if any mathematical foundation. The author has succeeded in presenting the various phases of the subject necessary for these groups in a simple and understandable manner. The numerous illustrative problems that are worked out in detail with each step clearly indicated and the results checked will be a great help to the beginner who is without any other guidance. For the most part the mathematics is applied to electrical problems of practical value to the reader. The book contains an unusually large number of problems by means of which one can test his ability to solve them. Answers for many of them can be found in the back. The tables which are included in the Appendix will prove convenient. The author has departed from standard conventions in a number of cases among which are: using a small rectangle instead of a short line for the negative battery element; "I" is shown flowing in the opposite direction to that universally used and in conflict with that indicated by an ammeter placed in the line; using a rectangle for instruments with binding posts at the top, instead of circles with leads brought out at any convenient place. The latter frequently results in unnecessarily complicated diagrams. It would have been wiser to use the generally accepted symbols.

H. M. TURNER
Yale University
New Haven, Conn.

The Radio Amateur's Handbook, Special Defense Edition

Published by The American Radio Relay League, West Hartford, Conn. 280 pages+8-page index. 301 figures. $6\frac{1}{2}\times9\frac{1}{2}$ inches. Price, $1.00.

The Special Defense Edition of the Handbook is a revised edition designed primarily to serve as a textbook for defense training courses such as are given in numerous high schools, community centers, etc., throughout the country. It retains all of the basic theory included in previous editions of the Handbook but omits most of the apparatus construction details primarily of interest to the radio amateur.

A very good chapter has been added dealing with the elementary operations of simple mathematics.

There is also a section dealing with the learning of the telegraph code, and some suggestions for a classroom code table.

The material is well chosen to be of special value to those seeking to qualify as radio operators and it is conveniently arranged and clearly presented.

H. O. Peterson
R.C.A. Communications, Inc.
Riverhead, L. I., N. Y.

Acoustics of Music, by Wilmer T. Bartholomew

Published by Prentice Hall, Inc., 70 Fifth Avenue, New York, N. Y., 1942. 242+xvi pages. 42 illustrations. $6\frac{3}{4}\times9\frac{1}{4}$ inches. Price $3.00.

Although both the musician and the acoustical engineer deal intimately with the same basic phenomena, their points of view have differed greatly and their contacts with each other have too often resulted in friction, with its inevitable product, heat. The present book, which is written from the musician's point of view, aims to acquaint musicians with the basic physical facts of acoustics as well as with the more subtle psychophysiological factors with which the musician is familiar through experience, but concerning which his opinions may have outstripped his knowledge. The author, who is a member of the faculty of the Peabody Conservatory of Music, is to be congratulated upon having produced such a well-written, readable, and informative exposition of the subject. The treatment is simple, clear, and nonmathematical and while leaning, as it should, toward the language of the musician rather than that of the engineer, the book still makes interesting reading for the latter, although it may occasionally send him to a dictionary of musical terms.

The author, in his preface, at once does much to place himself in the good graces of his scientific readers by statements such as the following: "... although written from the musician's standpoint, and with, I hope, a constant awareness of aesthetic factors too subtle and too tenuous to be caught in the scientist's sieve, it does eschew the typical pseudo-mystical misinformation that weakens so many texts written by musicians lacking either scientific training or a true mysticism. It does not go far into the scientific realm, but it attempts to be correct, up-to-date, and truly scientific in spirit as far as it does go."

In the body of the book, the author surveys, in his first chapter, the nature of vibration and its relationship to music, and then passes on to sound waves and their characteristics. Next comes a chapter on vibratory sources of sounds used in music, wherein are treated stretched strings, air columns, percussion, voice, and noise. The section on voice, the specialty of the author, has the ring of authority and, we suspect, is intended to exert a considerable debunking influence upon the voice-teaching profession. The manner in which one may obtain the relaxed, open throat which, the author emphasizes, is a primary requisite for good voice quality, is painstakingly explained, and even a bathtub-singing engineer should be able to improve his vocal performance from the study and application of this section.

Chapter 4 on harmony and scales is probably the only portion which will be found difficult reading for the engineer without musical training, and may require frequent reference to the musical dictionary for terms which are the everyday language of the musician. There follows a chapter on hearing; and the book concludes with a chapter on electrical recording and reproduction of sound, and electronic musical instruments. Here the radio engineer will find some interesting comments on the frequency and volume ranges of radio receivers, as well as some conclusions with regard to high-fidelity reception, although these comments lose some of their point with the advent of frequency modulation. A bibliography with some 138 entries appears in the back of the volume.

There are a number of errors which will be noticed by the engineer, but which may not greatly harm any musician who may accept them as fact. For example, on page 38 it is stated that the lowering of the natural frequency of a Helmholtz resonator by decreasing the size of the aperture is due to the slowing down by air friction of the piston motion in the opening. Resonance in rooms at low frequencies is, on page 39, mistakenly likened to that in Helmholtz resonators. The newer concepts of architectural acoustics are disregarded on page 72, where it is stated that it does not make a great difference in what part of a room acoustic-absorbing material is placed. On page 204, in a table attributed to Jeans, energy is expressed in watts. On page 209 the bar is defined in a footnote as equal to one megadyne per square centimeter. This is a good example of why the use of the term bar in acoustics is deprecated by the American Standards Association. The acoustic bar is equal to one dyne per square centimeter, but in all other fields it is defined as above. On page 212 the reference level of sound intensity (10^{-16} watt per square centimeter) is stated to be "that fraction of a watt per square centimeter which is indicated by the numeral 1 with sixteen ciphers after it."

In spite of these criticisms, this book will be found to be a valuable contribution in bridging, in an effective and interesting manner, two fields which have suffered much from isolationism. It may be read with profit not only by the musician but by the acoustic scientist as well.

Benjamin Olney
Stromberg-Carlson Telephone
Manufacturing Co.
Rochester, N. Y.

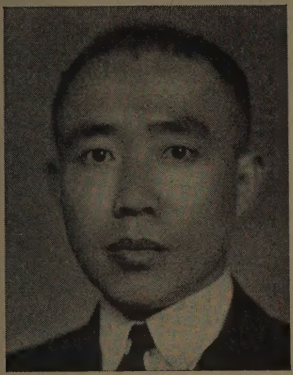
Rhombic Antenna Design, by A. E. Harper

Published, 1941, by D. Van Nostrand Company, Inc., 250 Fourth Avenue, New York, N. Y. 108 pages+3-page index+xv pages. 55 figures. $8\frac{3}{4}\times11\frac{1}{4}$ inches. Price $4.00.

This book deals with current design and construction practices relative to the rhombic antenna, which has found widespread application during recent years in the field of short-wave communications. Tabulated and graphical functions have been included to expedite design computations. Plans of typical transmitting and receiving antennas have been appended to indicate essential components and construction details. Typical directive diagrams and other performance characteristics are also given.

H. O. Peterson
RCA Communications, Inc.
Riverhead, L. I. N. Y.

Contributors



Chung-Kuei Chang

Chung-Kuei Chang was born on March 15, 1900, in Hopei province, China. He received the B.S. degree in physics from the National Peking University in 1924, and the engineer degree in electrical engineering from Stanford University in 1940. From 1929 to 1937, he was an instructor in physics at the Peking University. Mr. Chang is now doing research in radio communication at Stanford University.

❖

James Lawrence Fly was born at Seagoville, Dallas County, Texas, on February 22, 1898. He received his commission as ensign from the United States Naval Academy in 1920 and remained in the Navy until 1923 when he resigned. In 1926, he received the LL.B. degree from the Harvard Law School.

Mr. Fly was admitted to the Massachusetts and New York State bars in 1926, and practiced law in New York City until 1929. From 1929 to 1934, he served as a Special Assistant United States Attorney General acting as government counsel in actions involving restraint of trade under federal antitrust laws and regulatory measures under commerce power.

J. L. Fly

In 1934, Mr. Fly became general solicitor and head of the legal department of the Tennessee Valley Authority, and served in this capacity until 1937 when he became general counsel of the Tennessee Valley Authority.

President Roosevelt nominated him to be a member of the Federal Communications Commission on July 27, 1939, filling the unexpired term of the late Anning S. Prall. On September 1 of that year, he took his oath of office, at which time the President designated him as Chairman of the Federal Communications Commission. Reappointment for a full seven-year term occurred last July.

When the Defense Communications Board was created by Executive Order on September 24, 1940, Mr. Fly was made the Chairman. He has continued in that capacity since the Board of War Communications succeeded the Defense Communications Board.

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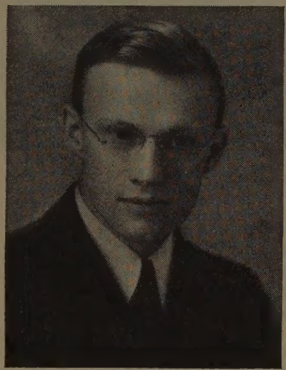
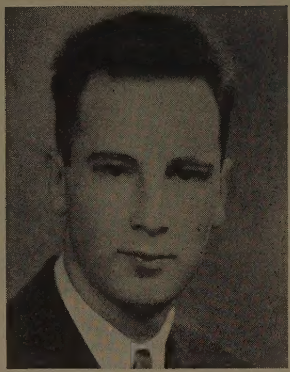


G. L. Fredendall

G. L. Fredendall (A'41) received the Ph.D. degree from the University of Wisconsin. From 1931 to 1936 he was at the University teaching electrical engineering, mathematics, and doing research work in mercury-arc phenomena. Since 1936 he has been with the RCA Manufacturing Company engaged in television research.

❖

Nathaniel I. Korman (S'38-A'39) was born in Providence, Rhode Island, on February 23, 1916. He received a B.S. degree from Worcester Polytechnic Institute in 1937. Working at Massachusetts Institute of Technology under a Charles A. Coffin Fellowship, he received an M.S. degree in electrical engineering in 1938. That same year he became a student engineer with the RCA Manufacturing Company. Since 1940, Mr. Korman has been employed as an engineer in the transmitter advanced development section of the special apparatus division of this company and has been concerned with frequency modulation and ultra-high-frequency problems. He is a member of Sigma Xi.



Nathaniel I. Korman

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Vepa V. Lakshmana Rao* (A'35) was born on May 12, 1911, at Vizagapatam, India. He obtained the B.E. degree from Madras University in 1932 and from 1932 to 1933, he was an apprentice engineer at the Pykara Hydro-electric Scheme. He was a research and postgraduate scholar in the Electrical Technical Department, Indian Institute of Science, Bangalore, 1933 to 1934, and in the Madras Government Electrical Department from 1935 to 1936. Mr. Rao received the D.I.C. degree from the Imperial College of Science and Technology, London, in 1938 for postgraduate research work in telecommunications. He served his apprenticeship with Messrs Philips', Holland, in 1937 and with the British Broadcasting Corporation in 1938 and received a diploma from the Marconi School of Wireless Communication, Chelmsford, in 1938. He was a senior shift engineer, H.E.H. The Nizam's State Broadcasting Service in 1939 and a lecturer in radio engineering, Indian Institute of Science, Bangalore, in 1939. Since 1939, Mr. Rao has been a radio engineer with

* Paper appeared in November, 1942, issue o the Proceedings.

Vepa V. Lakshmana Rao

M. Rettinger

the Provincial Broadcasting Government of Madras in charge of a laboratory and workshop; engaged in the purchase, testing, modifying, installation, and maintenance of radio sets and public-address systems in the rural and urban parts as a part of the Madras Government's Rural Broadcasting Scheme.

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M. Rettinger received from the University of California at Los Angeles the B.A. degree in physics in 1932 and the M.A. degree in 1934. Since 1936, he has served as an acoustic engineer for the RCA Manufacturing Company at Hollywood, California.

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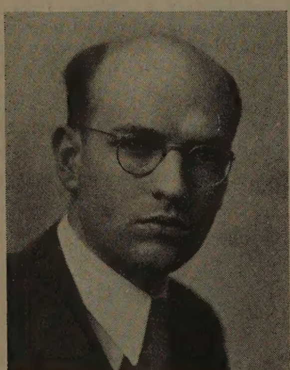
Elmer H. Schulz (A'38) was born at Lockhart, Texas, on October 30, 1913. He received the B.S. degree in electrical engineering in 1935 and the M.S. degree in

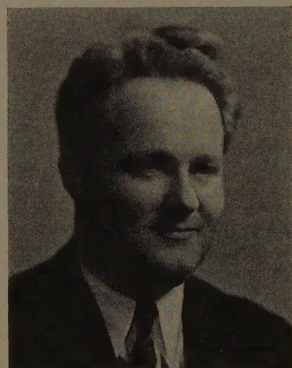


Elmer H. Schulz

electrical engineering in 1936 from the University of Texas. He was on the teaching staff of the electrical engineering department of The University of Texas from 1936 to 1942 when he joined the staff of the electrical engineering department of Illinois Institute of Technology. Mr. Schulz is a member of Tau Beta Pi and the American Institute of Electrical Engineers.

❖

Karl Troeglen (A'30-M'42) was born on August 17, 1908, in Kiel, Germany, and came to the United States in 1913. He has been active in amateur and commercial radio work since 1923. He was a marine operator on the Great Lakes during 1927



Karl Troeglen

and 1929 and a field engineer with the Universal Wireless Communications Company during 1929 and 1930. Since July, 1930, Mr. Troeglen has been with the Topeka Broadcasting Association, becoming chief engineer of that company in 1933. He was a member of the National Association of Broadcasters Engineering Committee during 1941–1942.

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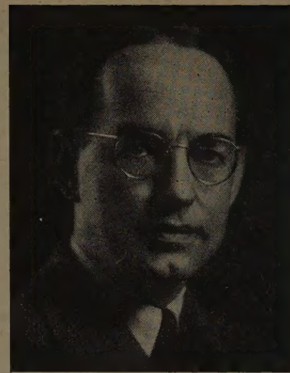
Arthur Van Dyck (A'13-M'18-F'25) was born on May 20, 1891, at Stuyvesant Falls, New York. He received the Ph.B. degree from Sheffield Scientific School, Yale University in 1911. From 1907 to 1910 Mr. Van Dyck was an amateur experimenter and commercial operator at sea. He was associated with the National Electric Signalling Company, Brant Rock, Massachusetts, 1911–1912; research department, Westinghouse Electric and Manufacturing Company, 1912–1914; instructor in electrical engineering, Carnegie Institute of Technology, 1914–1917; expert radio aide, U. S. Navy, 1917–1919;



Arthur Van Dyck

Marconi Company, Aldene, New Jersey, 1919–1920; in charge, radio receiver design, General Electric Company, 1920–1922. Since 1922 he has been with the Radio Corporation of America.

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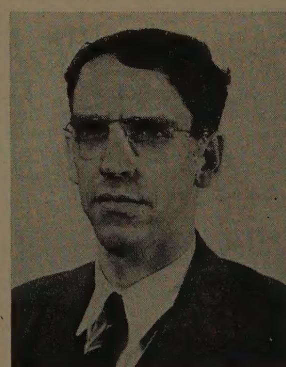
Karl R. Wendt (A'36) was born on January 3, 1906, at Coshocton, Ohio. He attended the Municipal University of Akron, Marquette University, and the University of Wisconsin. During 1928 and 1929, he was a research assistant in the chemistry department of the University of Wisconsin, and in 1929 and 1930 he was in the research laboratory of the Sun Oil Company. In 1930, Mr. Wendt joined the RCA Manufacturing Company and has been a member of the research department of that company since 1934 and is now located in the RCA Laboratories at Princeton, New Jersey. He is a member of Alpha Chi Sigma.



K. R. Wendt